Sewer Systems Module for Higher Professional Education

2009 / Version 2

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Preface to the English translation

The Sewer Systems Module for Higher Professional Education offers higher education material in the field of urban drainage and sewerage. This English translation is provided for English-language education in the Netherlands in this field. In addition this translation may help to inform and educate professionals outside the Netherlands. It gives an overview of planning, design and management of Western urban drainage in the Dutch context.

Central in this publication are the technology and design of sewer systems. These are placed in the context of urban water management and physical and policy developments.

Both the Dutch and English versions of the publication are distributed exclusively on-line and are available from www.rioned.org, www.kiviniria.net, and www.nlingenieurs.nl.

The Sewer Systems Module for HPE appears under the responsibility of KIVI Niria, the Dutch professional Association of Engineers. The publication is an initiative of a working group of teachers in the field of water management of 16 universities of applied sciences, and was produced by the Sewerage Working Group of NLingenieurs, the Dutch Association of Engineering Consultants. The RIONED Foundation, the Dutch umbrella organisation for urban drainage, facilitated the process.

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Den Haag / Ede, November 2009

1 Introduction

1.1 Purpose of this publication

Sewers and drains form a valuable part of the urban infrastructure. Mostly hidden from sight underground, they collect and transport the wastewater from residential, public, and industrial buildings, and account for the collection and disposal of a large proportion of the rain and snow that falls to earth. According to the readers of the British Medical Journal, the large-scale construction of sewers formed the single most valuable contribution towards the improvement of public health in history.

The technology involved in the calculation, construction, and maintenance of sewer systems is considered part of civil engineering. It has gradually grown into a major specialisation. Many engineers working for local authorities (municipalities), engineering companies, and water boards are involved in the design and construction of sewers and drains. They have developed sewer technology from an experience-based skill into a modern science.

Today the anticipated climate change, changing views on the design of urban infrastructures, and the desire to create a sustainable living environment in both urban and rural contexts mean that sewer engineers are constantly facing new challenges. Many new technologists will be needed in the near future to take up these challenges. The RIONED Foundation, which is a collaborative platform of public authorities, industry, and educational institutes for the upkeep of sewers and drains, has also been receiving information to the effect that there will be an increased demand for young and well-trained sewer engineers over the next couple of years.

In order to provide a new stimulus to *sewer technology training a Sewer Systems Module for Professional Higher Education* has been developed in a collaborative effort by three organisations. These organisations are the teaching department of KIVI/NIRIA, the leading industry association of and for engineers in the Netherlands, the Sewer Systems Group of NLingenieurs[1], which is the collaborative organisation of the professional association of consultancy and engineering firms, and the RIONED Foundation. The KIVI/NIRIA teaching department, in which all higher vocational institutes collaborate, is the principal of the project. The NLingenieurs Sewer Systems Group provides up-to-date professional knowledge on sewer technology through its associated engineering companies. The RIONED Foundation facilitates the project and provides the link with the users of sewer systems: water boards, municipalities, and the general public.

Together the organisations have made every effort to provide professional higher education students with expert information concerning the current state of the art of sewer technology. Although the information focuses on technology, to make the subject matter more accessible it has been placed in the wider context of urban water management.

The Sewer Systems Module for Professional Higher Education introduces students to the world of sewer technology with all its challenges. The collaborating organisations are both hopeful and confident that students will find in it the inspiration to take up a job in the sewer systems industry.

Ede, June 2008

1 The Sewer Systems Department of NLingenieurs is a collaboration of the following consultancy and engineering firms: Arcadis, DHV, Grontmij the Netherlands, MWH Global (formerly Syncera), Oranjewoud Engineering, Royal Haskoning, Snaterse Civil Engineering & Management, TAUW, Van Kleef Engineering, and Witteveen+Bos. These companies, the higher professional education institutes, and the RIONED Foundation have all contributed towards the realisation of the Sewer Systems Module for Higher Professional Education.

1.2 Authors

The Sewer Systems Module for Professional Higher Education was written by a group of authors. This group received support from an expert feedback group of professional higher education teachers.

The following people participated in the group of authors:

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Kees Snaterse coordinated the project for the Nlingenieurs Sewer Systems Workgroup.

1.3 Reading guide

Studying the Sewer Systems Module for Professional Higher Education will help students achieve the following educational targets:

- Knowledge of and insight into the position, importance, history, and developments of sewer systems for the collection and transport of wastewater and rainwater in built-up environments in the Netherlands.
- Knowledge about the way in which sewer maintenance and management are organised.
- The basic knowledge required for designing, specifying, and constructing a simple gravity sewer system.
- The knowledge and insight required to assess the basic principles of the hydraulic and environmental operation of a sewer system.
- The skill to perform simple hydraulic calculations to determine the inflow, outflow, storage capacity, and discharge of wastewater and rainwater, and to calculate the flows in sewer conduits as well as sedimentation inside sewers.

The Sewer Systems Module for Professional Higher Education is intended to be used in digital form, and is suitable for self-study. Students can develop the requisite knowledge, insight, and skills through self-study, and the various chapters provide the necessary educational material. A sufficient level of knowledge, insight, and skill will have been achieved if the self-assessment questions at the end of each chapter can be answered correctly.

The material is adapted to the level of knowledge of a second-year Higher Technical Education student of civil engineering. A basic knowledge of foundation structures, material properties, fluid mechanics, and water management is assumed.

In order to add interest to the subject matter, the material includes assignments. Their purpose is to provide students with additional insight into sewer maintenance and management by using the Internet or by visiting sewer projects. In addition, information text boxes provide background information about sewer systems in the Netherlands. The answers to the assignment questions and the content of the text boxes do not form part of the required reading, and are intended mainly to enliven the subject matter and to paint a more detailed picture of sewer maintenance and management.

The index can be used to look up the meaning of words, as it contains references to the pages where the keywords are defined and discussed in some depth.
Under 'Websites' students will find a list of web addresses that may prove useful in the study of the Sewer Systems Module for Professional Higher Education.

2 The history and importance of sewer systems

2.1 The importance of sewerage

In this day and age we tend to take sewers for granted in countries like the Netherlands, but we should not forget that the collection and transport of wastewater by our sewer systems and the subsequent treatment of the collected wastewater is a matter of vital importance. Sewers minimise the risk of contact between humans and fluid waste containing faecal bacteria that can spread disease. The entire process of collecting, transporting, and treating blackwater (wastewater containing human faeces) is known as sanitation. In order to emphasise the worldwide importance of proper sanitation the World Health Organisation declared the year 2008 to be the 'year of sanitation'.

2.1.1 Sewer systems and public health

In addition to personal hygiene, the most important means of reducing the incidence of infectious disease is by limiting the risk of people coming into contact with blackwater and by ensuring that reliable sources of drinking water are readily available to the general public. Creating and maintaining the separation between the human population and blackwater, and the responsibility for reliable drinking water sources form the subject of Public Health Engineering.

It is difficult to calculate exactly to what extent sewers (by collecting and transporting blackwater) and the availability of healthy drinking water contribute to our current level of public health. After all, in addition to the large-scale construction of drinking water and sewer systems in the western world, advances in medical technology and the general availability of public health services also play a major role in this success story. In order to get some idea of the contributing factors, table 2.1 lists a few key figures comparing the states of public health in Mali and in The Netherlands.

Table 2.1 Some key figures relating to public health

	Mali	Netherlands
Life expectancy (male)	45 years	77 years
Life expectancy (female)	47 years	81 years
Infant deaths due to diarrhoea	18.3%	0
Availability of sewers (rural)	42%	100%
Availability of sewers (urban)	71%	100%
Availability of good drinking water (rural)	21%	100%
Availability of good drinking water (urban)	3%	100%

This is not to suggest that the differences listed in the table can all be attributed to different levels of sanitation. The data were obtained from the web site of the World Health Organisation (WHO). Take a look at www.who.int/whosis/database/core/core_select.cfm, where you will find statistics covering 100 indicators of public health in all the countries of the world.

ASSIGNMENT
Using the WHO website mentioned, try to find out which factors other than sewer systems and drinking water really make a difference.

Figure 2.1 shows what a sewer in Bamako (the capital of Mali) looks like. It is no more than an open drain which, to put it mildly, does not provide the necessary barrier between humans and animals on one side and blackwater on the other.

It was not so very long ago that water-related diseases were endemic in the western world. Typhoid fever for example, the incidence of which is related to contact with blackwater, wasn't eradicated in the Netherlands until 1970. The example in the text box below illustrates how quickly we have become used to a life of comfort, making us forget the reason why sewers were built in the first place.

In August 2001 a local daily newspaper reported that a washing machine in a house in the Dutch town of Deventer had for several months been fed with water from the sewer system. The cause for this was found to be an incorrect connection between the overflow of a rainwater cistern and the wastewater sewer. This type of rainwater cistern forms part of a sustainable household water system and is used to collect rainwater from the roof of the house. After filtering, the water can be used to flush the lavatory and wash clothing.

The public health risks associated with the use of sustainable household water systems and the probability of incorrect installation are unknown quantities, as opposed for example to sea and river defences, for which the risks of failure are calculated in advance. A comparison of a sustainable system against a traditional reference set-up (based on an analysis of every conceivable incorrect connection; see figure 1) demonstrated that the risks of the sustainable type of system are significantly higher than those presented by a traditional set-up. Incorrect connections are particularly hazardous in household water systems because these feature two different supply systems, one for drinking water, the other for utility water (figures 1 and 2). A sustainable system also has individual disposal systems, with wastewater and rainwater being collected in separate sewers.

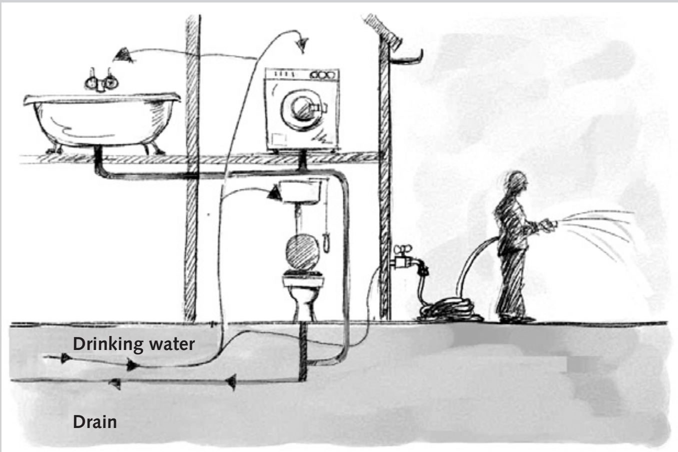


Figure 1 **Traditional robust system (single pipe systems for water supply and disposal) [RIZA, 2002]**

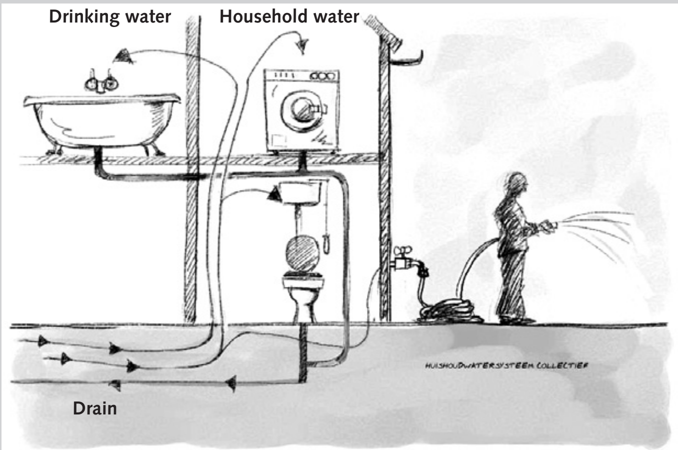


Figure 2 **Sustainable household water system (double pipe systems for water supply) [RIZA, 2002]**

Figure 2.1 Open sewer in Bamako, Mali (photo: F. Clemens)

In addition to reducing the risk of infectious disease, sewer systems play a major role in keeping our living environment dry. A wet environment has a detrimental effect on public health (fungi, asthma, rheumatoid arthritis, etc.). This is why, in addition to the correct disposal of wastewater, the disposal of excess rainwater is essential if a health living environment is to be created and maintained.

2.1.2 Sewers and the environment

Sewers provide a highly effective means of keeping wastewater away from the direct vicinity of humans and animals. However, this does not mean that the collected wastewater magically disappears.

Originally, sewers simply made sure that wastewater collected in built-up areas was disposed of in some place where it couldn't do much harm. This generally meant that the collected wastewater was discharged into open water, usually outside a town's perimeter, though occasionally within its walls. Although the nuisance level at the source was reduced, the method concentrated the problem in the open water. Today, the practice of releasing untreated wastewater into the environment has been almost eradicated in this country, and is banned by law. Wastewater from practically every built-up area is now transported to wastewater treatment plants. Nonetheless, it cannot be said that our sewer systems do not affect the environment, as will be shown in the following.

Newspaper article on combined sewer overflows (Trouw, 17-3-2005)

Riooloverstort op strand Egmond voorlopig open

DEN HAAG – De gemeenten Bergen en Beverwijk mogen hun riooloverstorten op de stranden van Egmond aan Zee en Wijk aan Zee blijven gebruiken. Dat heeft de Raad van State beslist in de rechtszaak die de twee gemeentebesturen hebben gevoerd tegen minister Peijs van verkeer en waterstaat. De minister droeg de gemeenten vorig jaar op de lozing van rioolwater in het zwemwater per april van dit jaar te beëindigen. De hoogste bestuursrechtbank vindt het lozingsverbod niet terecht omdat Bergen en Beverwijk in 2000 nog een nieuwe vergunning kregen om de riooloverstort te kunnen gebruiken. De Raad van State wijst er verder op dat de overstorten maar enkele keren per jaar in werking zijn.

Most sewer systems in the Netherlands are of the combined type. In other words, wastewater and rainwater are collected and transported together by a system of single pipes. See figure 2.2.

This means that the wastewater coming from lavatories, bathrooms, and kitchens, as well as the runoff from roofs and streets, are all collected in a single sewer pipe.

Since it is economically unfeasible to construct a system capable of accommodating the rainwater produced by extreme weather conditions, combined sewer systems include emergency outlets known as sewer overflows. These are the result of the simple decision that in the event of a sewer being unable to cope with the inflow of water, any excess should be discharged into open water rather than onto the streets. It goes without saying that the discharged water is far from clean. After all, the system contains a mixture of wastewater, rainwater, and dislodged sewer sediment. In modern combined systems, sewer overflows are called into service about 5 to 6 times a year on average, which is a significant improvement over the former practice of releasing all wastewater onto open waters. Even so, the effects on our open waters cannot be ignored:

- Depending on the type of open water, oxygen levels may drop to a point where fish start to die.
- The open water may become contaminated with bacteria that prevent it from being used for recreational purposes.
- Visual pollution may occur (lavatory paper, silt deposits, etc.).
- Persistent materials such as heavy metals and pesticides may be discharged. These accumulate in organisms and silt with detrimental long-term effects on biodiversity.

It wasn't long before these drawbacks were acknowledged and separated sewer systems were introduced in which wastewater and rainwater are collected and disposed of through two separate

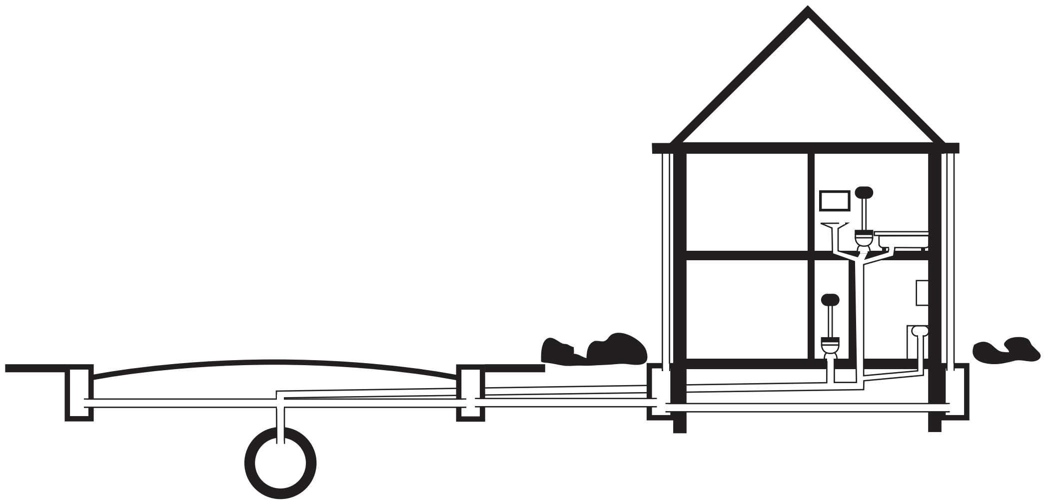


Figure 2.2 Combined sewer system

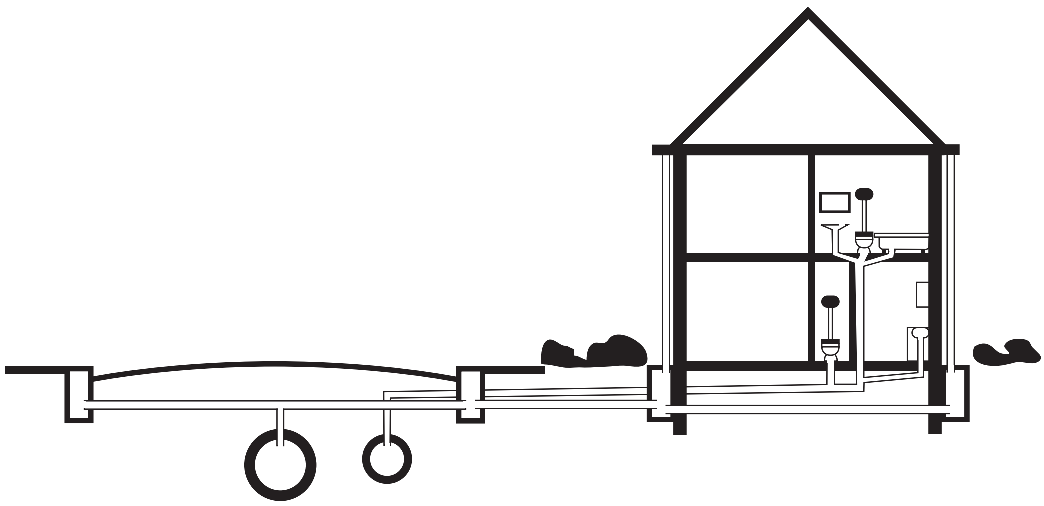


Figure 2.3 Separated sewer system

pipe systems. In a separated sewer system the wastewater from lavatories, bathrooms, and kitchens drains into the wastewater sewer system (known as a sanitary sewer, or foul sewer). The runoff from roofs and streets passes into the larger rainwater sewer (known as a storm drain).

There are clear advantages to the latter approach, since it prevents the discharge of diluted wastewater, and allows the hydraulic capacity of wastewater treatment plants to be reduced. The separated system comprises two separate pipe networks, one that carries wastewater, and one that carries rainwater. The latter network discharges its contents directly onto a suitable stretch of open water, or if possible, infiltrates the water into the subsoil. Of course this assumes that the collected rainwater is more or less clean. However, in urban areas this usually is not the case, with oil, fuel, atmospheric deposits, tyre rubbings, heavy metals, organic material etc. being washed from the street surface and ending up in open waters or in the soil.

Another weakness of this system is the risk of incorrect connections, resulting in rainwater flowing into the wastewater system, or vice versa. Both types of sewer set-up have their drawbacks. A hydraulic overload of a wastewater system can result in highly unpleasant situations with wastewater entering buildings, while a discharge of wastewater into the rainwater system will result in a direct discharge of wastewater into open waters, which is exactly what separated systems were designed to prevent in the first place. This is why improved separated systems have been introduced, in which, rather than releasing all rainwater directly into open water, the initial rainwater is mixed with wastewater and transported to a wastewater treatment plant.

An improved separated sewer system like the original separated system comprises a set of two distinct sewer networks, one for wastewater and one for rainwater. In the improved separated sewer system however, the two networks are interconnected, usually at manholes, to enable part of the rainwater to be directed to the wastewater treatment plant. This prevents the discharge into the environment of any wastewater that may have entered the rainwater system. It also helps to remove part of the detritus from the streets (known as the first flush) to wastewater treatment plants. In the event of continued large rainfall the remainder of the rainwater passes directly to open waters. The downside of this improvement is that approximately half the amount of all the rainfall we get ends up at the wastewater treatment plant, which undoes a major benefit of the original separated system. An increasingly popular option these days is to allow rainwater to infiltrate into the soil. It goes without saying that such schemes need to be offset against the risks of soil pollution and high water tables.

From 1983 to 1990 the National Sewerage and Water Quality Study Group (*Nationale Werkgroep Riolering en Waterkwaliteit, NWRW*) conducted a major study of the effect of sewage discharge[1] on the quality of surface waters.

ASSIGNMENT
Do you know what type of sewer your house is connected to? And do you have any idea which types of sewer systems exist in your town?

The Dutch Sewerage Atlas (Rioleringsatlas van Nederland) of 2005, which you can find on-line at www.riool.net, notes the following proportions of different sewer systems in Dutch urban areas in early 2005: 75% combined, 18% separated, and 7% improved separated.

These figures can do with some further qualification:
The average historic town centre contains 85% combined sewer systems and 15% separated sewer systems.

The average older city district contains 55% combined sewer systems, 25% separated sewer systems, and 20% improved separated sewer systems.

The average modern residential area contains 17% combined sewer systems, 18% separated sewer systems, and 65% improved separated sewer systems.

The average industrial estate contains 40% combined sewer systems, 30% separated sewer systems, and 30% improved separated sewer systems.

With regard to the effect of the type of sewer system on sewage discharge, the NWRW was able to draw some conclusions from the study results. Although part of these conclusions had been reached before, they had not previously been backed up by measurements or calculations. The calculation results were confirmed to some extent by the test readings.

1 Sewage discharge comprises the total of unwanted materials that enter the environment through the sewer system, and includes organically degradable materials, nutrients, heavy metals, pesticides, etc.

Although the study dates back a few years, further studies in recent years have not led to fundamentally different conclusions. The key findings are reproduced here:

- The annual sewage discharge from combined systems and that from separated systems are of the same order of magnitude.
- The lowest sewage discharge comes from improved separated systems.
- Sewage discharges should preferably take place into larger, non-stagnant waters such as rivers and canals.
- Direct discharge into open waters of rainwater from streets should be limited to low-traffic residential areas.
- If the quantity of overflowing water needs to be limited, the most effective way of doing so is by including a storage and settling basin between the overflow and the surface water. A storage and settling basin in a combined sewer system provides an effective means of reducing both sewage discharge and wastewater discharge into open waters. It is a facility in which rainwater mixed with wastewater can be temporarily stored and in which the waste materials contained by the wastewater can settle.

2.1.3 Sewer systems and the quality of the built environment

Most towns and villages in the Netherlands originated on raised sites. Many place names contain elements that reflect the elevated nature of the location. In some cases the inhabitants themselves constructed artificial mounds on which to build their houses to protect them from flooding. The rainwater in these places could usually be handled by natural means.

As the population increased in numbers and urban agglomerations grew in size, expanding city limits meant that previously unused areas had to be made available for building even though they were not naturally suited to the purpose. In these expanding conurbations, sewers were essential for the disposal of wastewater. In addition to this, sewer systems began to play a major role as a means of carrying rainwater away from built-up areas and effectively draining areas that were naturally wet. These low-lying areas could never have been made habitable without the construction of sewers and the availability of stretches of open water into which the sewer systems could unload their contents.

Clearly the Netherlands would not be suitable for habitation without sewerage, which is why the construction and maintenance of sewer systems merits our close attention. The cost of constructing sewer systems, drainage, and stretches of open water accounts for about 20% to 40% of the total cost of preparing a site for construction and habitation.

2.2 History

2.2.1 Pre 1970

The history of sanitation literally goes back as far as human memory. We know that sewer systems were in use in Mesopotamia several thousands of years B.C. Remains of sewer systems dating back to 1500 B.C. have been discovered in the ruins of Knossos on Crete. However, any history of sanitation usually points out the engineering works completed by the Ancient Romans, not least because the results of their efforts have been preserved remarkably well in a number of places.
It has become customary to include accounts of the Cloaca Maxima, a sewer, part of which still remains, that was constructed by the Romans to carry wastewater and rainwater from the city of Rome into the river Tiber. The permanent quality of its structure is always a popular topic. Although the Cloaca Maxima is a prime example of the know-how and skills the Romans could bring to bear when it came to designing and building large hydraulic structures, it does not do justice to the high

level to which the Romans had managed to elevate public health technology. Excavations, in particular those at the towns of Herculaneum and Pompeii, have provides us with ample information about the high standards of Roman engineering.

The excavations at Herculaneum and Pompeii (Jansen, 2001 *Water in de Romeinse Stad. Pompeji – Herculaneum – Ostia.* [Water in the Roman City. Pompeii – Herculaneum – Ostia.], Publ. Peeters, Louvain (Belgium), 249 pp., ISBN 90-429-1118-2) have shown that the inhabitants initially secured their supply of water from small rivers. In addition to this they used groundwater and collected rainwater. They also transported water from the mountains by means of an aqueduct, a facility that was probably introduced after the Romans had taken over the administration of the towns in the first century B.C.

Figure 2.4 Street with public water supply point in Pompeii (photo: F. Clemens).

The rainwater from the roofs was collected in an impluvium, a recessed area in the floor of the atrium. From there the water was piped to a cistern. Calculations show that the water collected in this way would be sufficient to satisfy the drinking water needs of 5 to 6 people. It should be noted that only the houses of the rich featured an impluvium in addition to a well from which groundwater was drawn. The less wealthy relied mainly on groundwater.

The construction of the aqueduct completely changed the situation, as large quantities of water suddenly became available. Water towers were constructed to distribute the water to all parts of the town. Lead pipes were introduced to carry the water into the houses. Those who could not afford to be connected to the water mains got their supply from public fountains.

The various different water supply systems coexisted, in all probability to ensure a steady supply even in dry periods and to overcome fluctuations in the aqueduct supply. We know for certain that the aqueduct needed to be cleaned at regular intervals, at which times the water supply would be cut off completely. Buffers to bridge these periods probably were not kept, though Ostia, the port of Rome which fell into decline in the third century A.D., had water cisterns that were probably used to bridge periods of low water levels.

Practically every house in Roman cities included a lavatory, often not just on the ground floor, but also on upper floors. Some houses featured several lavatories, while larger houses sometimes boasted lavatories with multiple seats. The waste from the lavatories was channelled into cesspits, and in some cases into sewers following the construction of public drinking water supply systems. Houses connected to the public water supply often featured lavatories with piped water for flushing and personal hygiene, as did public conveniences.

Faeces and urine from the lavatories were collected because they were valuable commodities. The faeces were used as fertiliser, and the urine was used in the production of leather and for dyeing wool.

Practically every street had a sewer running under it whose primary purpose was to carry off the wastewater produced by lavatories and kitchens, as well as the overflow from impluvia and fountains. The rainwater from roofs ran both above ground along the street, and underground. Allowing rainwater to drain away along the surface of the street is a highly practical and economical solution!

As far as we know the wastewater wasn't treated in any special way. There was probably little need to do so, for with the exception of Rome itself Roman towns were small compared with modern agglomerations, and the waste flows were of little import in today's terms. Rome discharged its wastewater straight into the Tiber, a comparatively large river that probably had little trouble coping with the inflow of wastewater.

The public water supply and sewerage, like all sanitary facilities with public access, were managed by the local authorities. The citizens were responsible for maintaining any facilities on private property. The Romans and their predecessors built and maintained first-rate facilities to ensure that towns could provide excellent living and working environments.

The facilities discovered during excavations in the towns of Herculaneum, Pompeii, and Ostia were of a quality that many modern cities only just manage to equal. It is clear that the Romans raised public health engineering to levels of great perfection. In cases where insufficient knowledge of hydrology, hydraulics, and structural engineering prevented them from designing a pipe system that would do the job, practical solutions were introduced. The only point of criticism would have to be that the Romans didn't know as we do that piping drinking water through lead pipes, and drinking wine from lead beakers, could cause lead poisoning.

The overthrow of the Roman Empire by the invading Germanic hordes had a disastrous impact on the water culture of the time. As existing skills and knowledge were no longer passed on and structures erected by the Romans fell into disrepair, entire water supply systems went to ruin, and sanitation facilities were eventually reduced to their most primitive form.

Europe in the Middle Ages remained a dark place. It was a time in which towns had no public water supply apart from a few public wells. Flushing lavatories were no longer in use, and personal hygiene sank to low levels. The result was a considerable risk of ingesting germs with drinking water, which led to protracted epidemics of cholera, typhoid, and plague.

Medieval conditions still prevailed in many towns at the beginning of the twentieth century. Sewers, if any, were rudimentary. In Amsterdam, the authorities repeatedly urged its citizens not to let water from inside houses flow freely into the streets, and to direct it instead into sewers under the streets from where it could be discharged into the canals.

At around 1600 the theoretical knowledge of fluid mechanics and hydrology started to develop rapidly. By the mid-nineteenth century the theory has advanced sufficiently to allow sewer systems to be developed based on rational considerations.

The nineteenth century saw the construction of sewers for economical reasons and to enable detritus to be flushed from the streets. This stemmed from the discovery that workers were more productive if they were healthy and lived in an environment from which waste was removed. In the English Midlands, the birthplace of the Industrial Revolution, factory owners built model housing estates, complete with sewer systems, to house their workforce, an investment that repaid for itself over and over again as productivity increased. The long and the short of it was that public health was worth a lot of money!

The large-scale construction of public sewer systems did not start until the mid-nineteenth century, albeit not without resistance in some places. London put off the construction of a sewer system until the stench in the City became so unbearable that Parliament had to suspend its deliberations because of what is now known as 'The Great Stink'. Major cities such as Paris soon followed suit. In the Netherlands too, several cities (including Arnhem and Amsterdam) started the construction of sewerage systems around the same time.

At the time, faeces were a valuable commodity, just as they had been in Roman times. In many cities human waste was collected in barrels and sold to farmers and market gardeners. In order to facilitate the collection of waste, sewers were constructed in some of the more densely populated town centres. It took quite a while for the barrel collection system to be laid to rest. The town of Delft for example took until the 1960s to complete the sewer system in its historic town centre.

The 1930s saw the introduction of sewer system projects on a large scale, mostly in the form of unemployment relief works during the depression years. Most of the sewers constructed during that period have now been replaced or have been scheduled for replacement.

2.2.2 Post 1970

The year 1970 marks a watershed in sanitation history in the Netherlands, being the year in which the Surface Water Pollution Act (*Wet verontreiniging oppervlaktewater*) became law. This resulted in a number of developments:

- The large-scale construction of wastewater treatment plants.
- The establishment of water treatment boards (all of which have now been amalgamated into all-in water boards).
- A permit system that also covered the discharge of sewage into open waters.

The introduction of the Surface Water Pollution Act resulted in a considerable improvement in the quality of surface water in the Netherlands. Round about 1980 most of the permanent wastewater discharge schemes had been brought under control and it became clear that the discharges from storm sewers were major factors in local pollution levels. The NWRW study mentioned previously led to insights that formed the basis for the total phasing-out of sewer overflows, some 15,000 in all, between 1990 and the present day. This operation has now been almost completed. In this context, attention should be drawn to a key concept introduced since the NWRW study, the so-called 'basic effort' (*basisinspanning*). The basic effort was defined by the CUWVO study group VI as the required modification of a combined sewer system such that the maximum admissible sewage discharge from the sewer system would never exceed the sewage discharge from a 'reference' combined sewer system. Local authorities were required to assess whether their system satisfied this requirement. If this was not the case, measures had to be taken to ensure the standard was reached.

The following measures could be considered in order to meet the basic effort requirements:
- Increasing the storage capacity of the sewer system by means of larger diameter pipes or storage basins.
- Increasing the handling capacity of sewage pumping stations, allowing more water to be transported to the wastewater treatment plant.
- Installing additional facilities directly behind the sewer overflow to reduce the discharge of sewage and the volume of overflowing water, for example a storage and settling basin.
- Disconnecting the flow of clean rainwater so it no longer passes into the wastewater system and instead drains into swales (Dutch: *wadi's*) or infiltrates directly into the soil.

ASSIGNMENT
On www.riool.net, use the Disconnection Product List to find out what a swale is.

Another large-scale project was to bring sanitation to remote areas. Under a number of different regulations, over the 1984–2000 period a number of so-called 'impractical connections' (think of remote houses, farms, and recreational facilities) were completed, bringing the sewerage connection percentage in the Netherlands to almost 100%. In these cases the systems weren't of the usual type as found in urban areas (with partially filled pipes laid at a drop to ensure that the contents will flow freely downhill under the influence of gravity). Instead they use pressure or vacuum systems. In a pressure sewer system, to most common variant these days, the wastewater from the house or farm is collected in a pumping well. A blackwater pump is then used to pump the wastewater from the pumping well through a fully filled pressure pipe and into the normal public wastewater system.

During the mid-1990s it was realised that draining clean rainwater into the wastewater system and then to a wastewater treatment plant is not very productive, and that the two systems should preferably be disconnected. The government has recently started to stimulate disconnection on the basis of the following considerations:
1. Disconnection reduces the flow of water to a wastewater treatment plant and so reduces the hydraulic load of the wastewater treatment plant.
2. It is better to keep the clean rainwater separate from the wastewater as much as possible, since after mixing and treating the two, the rainwater will have become less clean.
3. It is better to retain the rainwater that was formerly evacuated from the urban area, so it can be of use to local vegetation and prevent the area from drying out in times of drought.

On the other hand, there are several reasons why disconnection is not always the best option. These reasons are:
- Disconnection is expensive, and the disconnecting facilities must be well maintained in order to perform as intended.
- Infiltration must not result in excessively high water tables.
- Infiltration facilities must not introduce pollutants into the soil.

Disconnection therefore requires attention to detail, and it is the local authorities who have to balance the pros and cons and make the final decision.

2.3 Sewerage and its context

2.3.1 Sewerage as part of the water chain

The water chain is defined as the total of the systems that ensure the production and distribution of drinking water and the systems for the collection, transport, and treatment of wastewater.

Practically all the drinking water we use ends up as wastewater, so it is useful to know how much drinking water is used in the Netherlands and what it is used for. The current average drinking water consumption in the Netherlands is 128 litres per person per day, which on average is used for the following purposes: showers, 45 litres; lavatories, 32 litres; washing machines, 20 litres; washbasins, 6 litres; bath, 5 litres; dishwashing by hand, 3 litres; dishwasher, 3.5 litres; cooking, 3 litres; drinking water, tea and coffee, 1.5 litres; miscellaneous, including car washes and garden maintenance, 9 litres.

The sewer system forms part of the wastewater system, which in turn comprises the following:
- Interior sewerage.
- Exterior sewerage.
- Pumping stations and pressure pipes.
- Wastewater treatment plants.

Interior sewerage covers sanitary equipment and other appliances that use water (dishwashers, washing machines, etc.); soils stacks; connecting pipes; underground drains; and interior and exterior downpipes. In the Netherlands the interior sewerage is the responsibility of the owner of the building, with the responsibility passing to the local authorities at the site perimeter, where the pipes are usually fitted with an inspection cover. In the event of a blockage, the inspection cover can be opened to see which part of the sewer (private or public) is blocked, and who will have to pay for the cost of unblocking it.

Exterior sewerage comprises the actual system that transports the wastewater away from the source. In addition to underground pipes and manholes this system comprises service pipes that carry the wastewater and the rainwater to the public sewer or sewers, storm drains and their connecting pipes to the main sewer, overflows, weirs, pumping stations, storage basins, and storage and settling basins. In hilly areas in particular, streams or culverts may also form part of the sewer system, a situation that is found in a few locations in the east and south of the Netherlands.

2.3.2 Sewerage and the water system

Next to the water chain (see 2.3.1) we have the water system. The water system comprises the natural water systems (surface water and shallow groundwater).

A sewer system interacts with the water system at several points:
In the first place there is the mutual effect between the sewer system and the groundwater, since no sewer system can be constructed to be fully waterproof. In cases where the bottom of a sewer lies below the water table, groundwater can enter the sewer. This is the normal case in the Netherlands, and on a dry day groundwater can account for up to 50% of the total water flow. This draining action lowers the groundwater table, which can cause damage to building foundations. The effect on timber piles can be disastrous, for if the pile heads extend above the water table they will dry out and may start to rot, possible resulting in subsidence. More information on this subject can be found at www.platformfundering.nl. Older sewers (short pipe sections, low-deteriorated joint fillers) are to blame in particular, which is why it is to be expected that the problem will be solved in the near future as a result of the current large-scale sewerage refurbishing operations. As leaky sewer pipes are replaced, the resulting loss of the sewer’s draining action may result in higher water tables.

If on the other hand the water table tends to be lower than the sewer pipe, leaky sewers can spill their contents into the groundwater and contaminate it.

Another interaction is the one between sewerage and surface water. We have already seen that torrential rains can occasionally result in the discharge of (diluted) wastewater into surface waters. This affects the quality of the water of course, but if the overflow is discharged into a small body of water, it will also affect the quantity of the water, and may even cause problems with the drainage capacity of the surface water. Vice versa it can happen, as it often does in the western parts of the Netherlands, that as a result of subsidence or excessively high water levels, surface water enters a sewer though an overflow. This is to be avoided of course, since the sewer will simply convey the surface water to a wastewater treatment plant, which becomes less efficient as a result. The surface water also takes up space in the sewer system, thereby reducing its holding capacity so that in the event of heavy rains the point will sooner be reached when wastewater will be discharged into surface waters.

All in all there are many interfaces between the water and wastewater chains and the water system, a fact that should be kept in mind when designing and maintaining sewer systems.

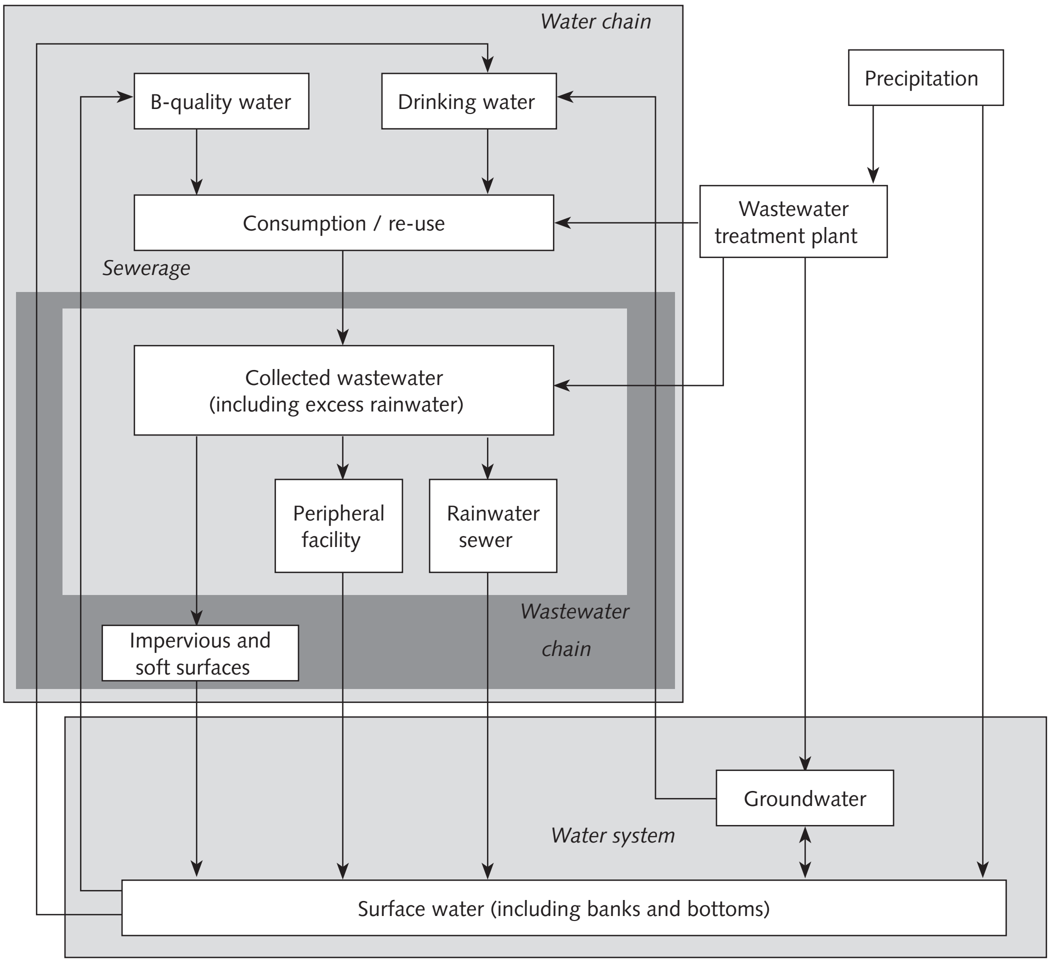


Figure 2.5 **Sewerage as part of the water chain and its interactions with the water system**

Self-assessment questions for chapter 2

1. What is the importance of sewerage to public health in the Netherlands? Give a short account of how proper sanitation levels were achieved in the Netherlands.
2. A number of pollutants can enter the environment through the sewer system. Name the key pollutants, their distribution paths, and the possible impact on the environment.
3. Describe and sketch a sectional view of a typical improved separated sewer system, indicating in particular how the system works.
4. Sewer overflows and combined sewer systems are inseparable. Describe what sewer overflows are and why they are inseparable.
5. According to you, why is it that the annual sewage discharge from combined sewer systems is roughly equal to that from separated sewer systems?
6. Did the Ancient Romans have wastewater treatment plants? If not, what happened to the wastewater containing the faeces and urine?
7. What happened in the 1970s to make us distinguish sewer systems constructed before then from those constructed at later dates?
8. What does it mean when a combined sewer system ‘meets the basic effort requirement’? Name a number of measures that can help to achieve the ‘basic effort requirement’.
9. What does disconnection involve? Name a few benefits and drawbacks of disconnection.
10. Describe the water chain and the wastewater chain from start to finish, and name the pipe systems used in succession.
11. In old town centres, sewerage can cause the water table to become excessively low or high. Name the main causes for this, and describe the possible effects.

3 Developments

This chapter looks at the developments in sewer management. Section 3.1 discusses contextual developments, i.e. developments in the outside world that directly affect sewerage. The next sections outline policy developments, both European and national, in the form of legislation, government policy, and plans. The final section takes a brief look at a number of technical developments.

3.1 Contextual developments

3.1.1 Climate developments

Climate can be defined as the average weather conditions in a certain region over a certain period. The climate tells you what to expect of the weather, how long and how heavily it may rain for example, and when and for how long it will be dry. These are issues that also affect the way our sewers work.

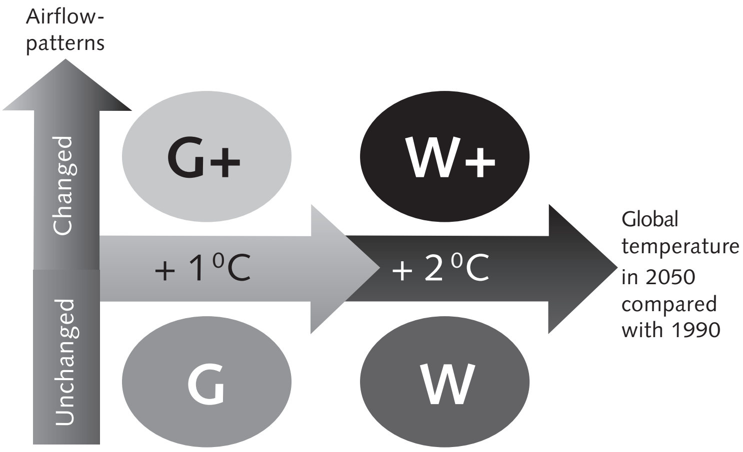
In the past, sewers were constructed on the basis of a certain knowledge about the local climate, which dictated how much rain the system should be able to cope with to prevent water flooding the streets, and how much water could overflow into surface waters. These are issues that need to be addressed when assessing the performance of a sewer system.

Climate change has become a hot item over the past few years. Factors such as the greenhouse effect cause the world around us to change. If rainfall increases, roads will flood more easily and more often, and incidents involving emissions of pollutants from sewer overflows may become more frequent.

On an international scale the IPCC[1] is monitoring the effects of climate change. Once every five or six years the IPCC assesses what we know about the climate and climate change, and what effect human activities have on the climate. The results are published in a report, which the Royal Dutch Meteorological Institute (*Koninklijk Nederlands Meteorologisch Instituut, KNMI*) translates for the Dutch situation. The Institute has defined four different climate scenarios for the Netherlands:

1 IPCC = Intergovernmental Panel on Climate Change (not to be confused with IPPC, Integrated Pollution Prevention and Control)

Figure 3.1 Climate scenarios



G	Moderate	Global temperature rise of 1 °C in 2050 relative to 1990 No change in airflow patterns in Western Europe
G+	Moderate +	Global temperature rise of 1 °C in 2050 relative to 1990 + warmer and wetter winters due to more westerly winds + hotter and drier summers due to more easterly winds
W	Warm	Global temperature rise of 2 °C in 2050 relative to 1990 No change in airflow patterns in Western Europe
W+	Warm +	Global temperature rise of 2 °C in 2050 relative to 1990 + warmer and wetter winters due to more westerly winds + hotter and drier summers due to more easterly winds

These climate scenarios provide a framework for ideas about further research and discussion.

The important thing for us is to see how these changes will affect sewer systems. The purpose of a sewer system is to collect and transport (urban) wastewater and to collect and dispose of rainwater from roofs and streets. The performance criteria which the sewer system must satisfy (for example how often we can accept water flooding a street) are laid down in the Municipal Sewerage Plan (*Gemeentelijk Rioleringsplan, GRP*).

For Northern Europe, the Royal Dutch Meteorological Institute forecasts an increase in winter precipitation of between 5% and 20%. Although most of this will fall in Scandinavia, more southerly regions will also suffer the effects to some extent. The expectation is that extreme occurrences of precipitation in particular will increase both in intensity and in number, which in turn will affect urban water management and sewerage.

In 2007 the RIONED Foundation published a memo under the title, 'Climate change, heavy rain, and sewerage' (*Klimaatverandering, hevige buien en riolering*). The main conclusion was that it is inefficient to design sewer systems to be able to cope with the highest conceivable peak load. Sewer systems are designed in accordance with the performance criteria laid down in local municipal sewer plans. They should be properly maintained so they will be able to do what they were designed to do. Increasing the capacity of a sewer system offers only a partial solution. In order to cope with the effects of climate change, additional measures in the public domain will also be required, such as reintroducing pavement kerbs and lowering street levels to make sure they will be able to accommodate excess water in an emergency, increased water retention facilities in the public domain, underground water buffering facilities, extended areas of open water, etc.

"RIONED Foundation's vision – Climate change, heavy rain, and sewerage"
As a result of climate change, heavy rainfall will become an increasingly common as well as increasingly violent phenomenon. Every scenario published by the Royal Netherlands Meteorological Institute shows an increase in rainfall. The traditional sewer systems will not be able to cope with these large quantities of sudden precipitation in all places at once, since they were not designed to be. The purpose of a sewer system is to collect and dispose of the runoff from roads and roofs during periods of normal rainfall. If damage is to be prevented in the event of large downpours, additional measures will be required, such as infiltration into the soil, overflows into open water, and short-term storage on roadways or elsewhere in the public environment.

Below is some information about extreme precipitation figures taken from the Royal Netherlands Meteorological Institute publication, 'The new statistics for extreme precipitation' (*De nieuwe statistiek voor extreme neerslag*, Wijngaard et al., 2005).
Table 3.1 lists precipitation levels and the frequencies with which these were exceeded, based on the full rain readings provided by the Royal Netherlands Meteorological Institute at De Bilt.

	Hours				**Days**			
	4	**8**	**12**	**24**	**2**	**4**	**8**	**9**
10 × per year	9	12	13	15	19	–	–	–
5 × per year	12	15	17	21	26	33	43	45
2 × per year	16	20	23	28	35	45	61	64
1 × per year	21	24	27	33	41	52	71	75
1 × per 2 years	25	29	32	39	48	60	81	86
1 × per 5 years	31	36	40	47	58	71	94	99
1 × per 10 years	36	41	46	54	65	80	103	109
1 × per 20 years	41	47	52	61	73	89	113	118
1 × per 25 years	43	49	54	63	75	91	115	121
1 × per 50 years	49	56	61	71	84	100	124	130
1 × per 100 years	55	62	68	79	92	109	133	138
1 × per 200 years	61	69	75	87	101	118	141	146
1 × per 500 years	71	79	86	98	113	130	152	156
1 × per 1000 years	78	88	95	108	123	140	159	163

Table 3.1 Precipitation levels in millimetres for a number of durations (from four hours to nine days) and the frequencies with which these were exceeded

Source: (Wijngaard, J., KNMI, Kok, M., HKV Lijn in water, Smits, I., KNMI, Talsma, M., STOWA, 2005, Nieuwe statistiek voor extreme neerslag; H_2O, Tijdschrift voor watervoorziening en waterbeheer, vol. 38 no. 6, 25 March 2005.)

The following important websites provide information about the climate and water/sewer systems:
- www.uvw.nl
- www.knmi.nl
- www.riool.info

ASSIGNMENT
Find out if (and if so, how) climate effects are being anticipated in your own town. (You could look up the municipal website, or phone an information number.)

3.1.2 Developments in spatial planning

The management of sewer systems increasingly overlaps the field of spatial planning. It has traditionally shared common ground with road management, since road surfaces need to be broken up to provide access to any sewers buried underneath. In addition, the rainwater from most roads and other impervious surfaces ends up in sewers.

The areas of overlap are still increasing. Any plans for above-ground rainwater drainage facilities must be developed in close collaboration with the local Department of Public Works. Examples of overlap are:
- Street-level rainwater drainage facilities must be designed to cause the least possible inconvenience to e.g. users of wheelchairs and walkers.

- Speed bumps in roads can affect rainwater drainage.
- The introduction of swales also affects the layout of our living environment. Swales don't make good sites for children's playgrounds. A swale is a surface depression in which rainwater can collect to infiltrate into the soil. Most swales are planted with grass or rushes. Swales help prevent the soil from drying out, provide additional buffer capacity in the event of excessive rainfall, and contribute to the improvement of water quality.

Environmental planning affects the capacity of the built-up environment to retain rainwater. Large expanses of impervious surfaces cause rapid drainage of rainwater, whereas the use of vegetation makes it possible to delay the need for rainwater drainage. Therefore, spatial planning also dictates the performance required from a sewer system, a fact that must be kept in mind as it affects design and maintenance requirements.

The impervious surface area in our built-up environment has been steadily increasing for many years, placing an ever heavier strain on our sewer systems. Another noticeable effect is the increased risk of flood problems caused by improved access to shops and other buildings for the disabled. Many thresholds and curbs have disappeared in our drive to level all publicly accessible areas, so in the event of heavy rainfall water can more easily enter the premises than before. The sewer system often gets blamed for this, but the actual cause of the problem is the way in which our public spaces are being designed and laid out.

3.2 Policy developments

Since much of our national legislation is based on European law, this section starts by looking at European legislation, which ranks higher in the hierarchy than national and local legislation. After the European legislation, a number of national and local laws relevant to sewerage will be discussed, and we will take a look at policy developments, types of planning, and standardisation.

3.2.1 Legislation

European Urban Wastewater Directive

The purpose of the urban wastewater directive (91/271/EEG, 21 May 2001) is to protect the environment against the adverse effects of the collection, treatment, and disposal of urban wastewater (domestic wastewater, rainwater, and part of the industrial wastewater) and the treatment and disposal of wastewater from certain types of industry. Sewer overflows are also affected by the directive.

The main points of the directive are:

- All agglomerations must have a collection system for urban wastewater. Up to 31 December 2000 this applied to agglomerations with more than 15,000 p.e.[2] and up to 31 December 2005 this applied to agglomerations with 2,000 to 15,000 p.e. Vulnerable areas were given priority (1998).
- The collection system requirements are listed in an annexe to the directive.
- Before disposal, the collected urban wastewater must be subjected to secondary treatment or an equivalent process. The wastewater treatment plant used for this purpose must meet the requirements laid down in the annexe to the directive.
- If possible, treated wastewater should be re-used, with minimal environmental impact.

2 p.e. stands for person equivalent.

The implementation of the directive in the Netherlands has been effected mainly within the framework of the Surface Water Pollution Act (*Wet verontreiniging oppervlaktewateren*) and the Environmental Protection Act (*Wet milieubeheer*). In other words, these acts form the implementation of the European directive in Dutch law.

European Water Framework Directive
We attach great importance to water quality in the Netherlands. Since water knows nothing about national boundaries, international agreements are necessary. This is why the European Water Framework Directive became law in late 2006 (Directive no. 2000/60/EG of the European Parliament and the Council of the European Union of 23 October 2000 establishing a framework for Community action in the field of water policy, PbEG L 327. The purpose of the directive is to ensure that the quality of European surface water and groundwater will be satisfactory in 2015.

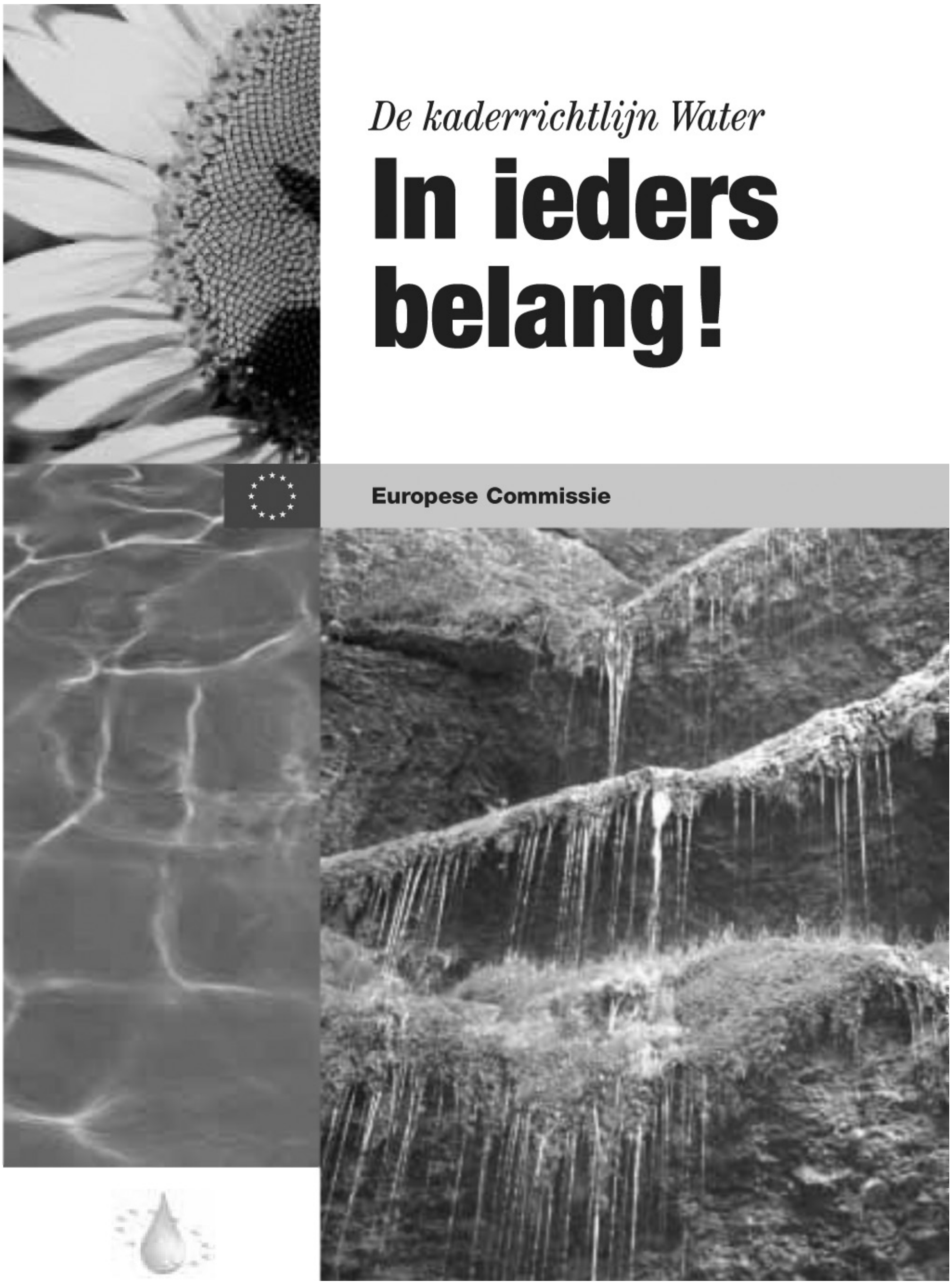


Figure 3.2 WFD brochure by the Dutch Ministry of Transport, Public Works and Water Management

The core elements of the legislation are:

- To protect all waters – rivers, lakes, coastal waters, and ground waters.
- To set ambitious objectives in order to ensure that all waters will have reached a ‘good condition’ by the year 2015.
- To introduce mandatory cross-border collaboration between countries and all the parties involved.
- To ensure that all the interested parties, including Non-Government Organisations and local communities, will actively participate in water management activities.
- To introduce mandatory water price policies, and to ensure that polluters foot the bill.
- To maintain a balance between environmental interests and the interests of those who depend on the environment.

Although the Framework Directive does not directly affect sewerage management, it does so indirectly. A future perspective will be defined for each catchment area, and a procedure for bringing the water system up to scratch will be formulated. Each of the local water boards will then use these to prepare future perspectives for their part of the catchment area. In order to ensure that the water quality requirements are met, all emissions of pollutants into surface water and groundwater will be subject to restrictions. Sewers also discharge into these water bodies. A major issue is formed by discharges from so-called diffuse sources. These discharges occur scattered over wide areas, and include the leaching of building materials, rainwater from pesticides and herbicides, etc.
Since the transport of these pollutants commonly takes place through sewers and (rainwater) drains, the legislation also affects our field.
For more information, see also www.kaderrichtlijnwater.nl.

Municipal Water Tasks Establishment and Funding Act
A major development in our national legislation is the Municipal Water Tasks Establishment and Funding Act (*Wet verankering en bekostiging gemeentelijke watertaken*), which came into effect on 1 January 2008 (Parliamentary records no. 30578). This act will not remain as a law of its own, but will be the title of an act that will amend three existing acts, the Municipalities Act, the Environmental Protection Act, and the Water Management Act. The salient points of the act are:

- A new sewerage tax in the Municipalities Act that constitutes an imposition rather than a retribution. A retribution is a remuneration for a service provided by the government to the advantage of the party paying the tax. In this way it differs from an imposition, which is not offset by an immediate quid pro quo. The latter offers legal advantages, which is expected to result in fewer legal proceedings. This enables municipalities to include the cost of collective maintenance service in the taxation imposed on citizens and businesses based in the municipality.
- The option of having a single tax (for wastewater, rainwater and groundwater combined) or two separate taxes for a) wastewater and b) rainwater and groundwater (laid down in the Municipalities Act).
- The mandatory management of urban wastewater (laid down in the Environmental Protection Act).
- The mandatory management of rainwater and the mandatory introduction of measures to prevent or limit, as much as possible, any ongoing adverse effects of the groundwater table on the use of the land (laid down in the Water Management Act).
- An order of preference for managing wastewater (laid down in the Environmental Protection Act).
- The option for municipal councils to introduce statutory regulations for managing rainwater and groundwater (laid down in the Environmental Protection Act).
- The option of using, under special conditions, individual wastewater treatment systems (*inrichtingen voor de individuele behandeling van afvalwater, IBA*) (laid down in the Environmental Protection Act).

Excerpts from the Municipal Water Tasks Establishment and Funding Act (Wet verankering en bekostiging gemeentelijke watertaken)

Mandatory management of urban wastewater (Zorgplicht voor stedelijk afvalwater)

Section 10.33

1. The local council or the mayor and aldermen are responsible for the collection and the transport of urban wastewater discharged on any property located within the boundaries of the municipality, by means of a public wastewater sewer leading to an establishment as referred to in section 15a of the Surface Water Pollution Act.
2. Instead of a public wastewater sewer and an establishment as referred to in the first subsection, separate systems or other suitable systems managed by a municipality, a water board, or a legal person charged with the management by a municipality or water board, may be used if the municipal sewerage plan these systems provide the same level of environmental protection.
3. At the request of the mayor and aldermen the provincial executive may discharge the municipality from the obligation referred to in the first subsection, if this is in the interest of the protection of the environment, for:
   a. part of the municipal domain located outside the built-up area, and
   b. a built-up area from which urban wastewater with a pollution level of less than 2,000 inhabitant equivalents is discharged.
4. The release from obligation referred to in the third subsection may be rescinded by the provincial executive if developments in the area for which the release was granted give cause for this. Any rescission will include a date before which the collection and transport of urban wastewater must be provided for.

Excerpts from the Municipal Water Tasks Establishment and Funding Act (Wet verankering en bekostiging gemeentelijke watertaken)

Mandatory management of rainwater and groundwater measures

Water management act, section 9a (Wet op de waterhuishouding)

1. The local council or the mayor and aldermen are responsible for the efficient collection of rainwater, insofar as the person disposing of it, intending to dispose of it, or bound to dispose of it, cannot reasonably be required to dispose of the rainwater on or in the soil, or in surface waters.
2. The local council and the mayor and aldermen are also responsible for the efficient processing of the collected rainwater. Processing of rainwater can comprise at least the following measures: storage, transport, useful application, reintroduction, whether treated or untreated, onto or into the soil or in surface water of collected rainwater, and the transport to an establishment as referred to in section 15a of the Surface waters pollution act.

Water management act, section 9b

1. The local council or the mayor and aldermen are responsible for taking measures in the public municipal domain for the purpose of preventing or limiting, as much as possible, any ongoing adverse effects of the groundwater table on the use of the land, insofar as taking these measures is effective and is not part of the responsibility of the water board or the provincial executive.
2. The measures referred to in the first subsection include the processing of the collected groundwater, comprising at least the storage, transport, useful application, reintroduction, whether treated or untreated, onto or into the soil or in surface water of collected groundwater, and the transport to an establishment as referred to in section 15a of the Surface waters pollution act.

No later than five years after the act comes into effect (i.e. before 2013) the local council must provide a Municipal Sewerage Plan (*GRP*) which in addition to provisions for urban wastewater will include the same for rainwater and groundwater.

Much more information about this act can be found in the Parliamentary records concerning the act, at the website of the RIONED Foundation, and in information provided by the Association of Netherlands Municipalities (*Vereniging van Nederlandse Gemeenten, VNG*), see the publication, *Van rioleringszaak naar gemeentelijke watertaak* ('From sewerage to municipal water management', Dutch only) and www.vng.nl (some English content provided).

Water act

Another major development is the introduction of the Water act (Parliamentary records no. 30818). The Water act will soon regulate the management of surface waters and groundwater, and will also improve the interaction of water policy and environmental planning. In addition the Water act will be a major step towards achieving such government objectives as reducing the amount of red tape.

The Water act replaces the following existing acts regulating water management in The Netherlands:

- Water management act (*Wet op de waterhuishouding*)
- Water defences act (*Wet op de waterkering*)
- Groundwater act (*Grondwaterwet*)
- Surface waters pollution act (*Wet verontreiniging oppervlaktewateren*)
- Sea water pollution act (*Wet verontreiniging zeewater*)
- Land reclamation act of 14 July 1904 (*Wet droogmakerijen en indijkingen*)
- Hydraulic engineering works management act (*Wet beheer rijkswaterstaatswerken*)
- Public works act of 1900 (*Waterstaatwet 1900*)
- Wrecks act (*Wrakkenwet*; this may also be integrated by means of introduction legislation).

In addition the water bottom cleaning regulation will be moved from the Soil protection act to the Water act. More information can be found at www.waterwet.nl and www.helpdeskwater.nl.

The Underground networks information exchange act

Network managers and parties carrying out groundwork will be subject to a statutory system of cable and pipeline registration as well as location consultation prior to carrying out groundwork. The The Underground networks information exchange act (*Wet Informatievoorziening Ondergrondse Netwerken, WION*) will affect all managers of cables or pipeline systems, which includes sewerage managers. Therefore, the sewerage records must be kept in perfect order.

Discharges

The government is currently replacing individual permit-based regulations with general regulations whenever possible.

The general regulations for discharges have been, or will be, included in the following three resolutions.

1. Domestic wastewater discharge resolution (*Besluit lozing afvalwater huishoudens*; 01-01-2008)
2. Resolution for discharges from industrial establishments (*Activiteitenbesluit voor lozingen vanuit inrichtingen*; 01-01-2008)
3. Non-industrial discharges resolution (*Besluit lozingen vanuit niet-inrichtingen*)

1. The Domestic wastewater discharge regulation focuses on the discharges of domestic wastewater. The resolution replaces the old Soil protection discharges resolution and the Domestic wastewater discharge resolution of the Surface waters pollution act, among others. The resolution contains general regulations for the discharge of wastewater by private individuals. It means that households do not require a permit or exemption for discharging their wastewater. This covers e.g. the wastewater coming from lavatories, kitchens and bathrooms, precipitation (rain, snow, hail), water used to wash cars or rinse dustbins, groundwater that has been collected and is being disposed of in order to prevent problems due to excess groundwater, water from swimming pools in gardens, etc. The resolution does not include any concrete regulations for the discharge of the most common wastewater flows, but it does stipulate a so-called management responsibility. This indicates that in the event of a discharge any adverse effects on the quality of the soil and the surface water must be kept to a minimum. In addition, the proper operation of the sewerage and wastewater treatment plant may not be impaired. Leftover paint, for example, may not be poured down the drain, but must be disposed of as domestic chemical waste. The authorities responsible for the quality of the surface water (the local council or water board, depending on whether the discharge takes place into a sewer, into the soil, or into surface water) can lay down network regulations to provide a last-ditch defence. Consider for example a house with a roof constructed of untreated metal. Leaching from the roof in times of rain could affect the environment, in which case the water board can introduce measures to either reduce the leaching effect, or prevent the leached material from reaching the groundwater.

2. The industrial discharges resolution focuses on discharges from commercial establishments. This resolution covers all discharges from commercial establishments into surface water, into the soil, and into sewer systems. The rules have been arranged so as to fit the point of view of businesses rather than the authorities. The resolution is based on the Environmental Protection Act and the Surface waters pollution act, both of which will be replaced with the Water act. The industrial discharges resolution also implements part of the rainwater policy as laid down in 2004. The industrial discharges resolution distinguishes between direct and indirect discharges. With direct discharges the wastewater is discharged directly into the environment (surface water or soil). Indirect discharges can be subdivided into discharges into a rainwater sewer and discharges into a foul water sewer. For more information, see '*Activiteitenbesluit*' at www.infomil.nl (Dutch language only).

3. The Non-industrial discharges resolution was not yet available at the time of this publication. These general regulations will control discharges from sewer overflows and storm drains, among other things.

For more information, see the '*afvalwater*' topic at www.minvrom.nl (Dutch language only).

Water board statutes
Water boards have the option of specifying local regulations for the area under their authority (within the framework of the national and provincial regulations). These regulations are laid down in a statute (Dutch: *keur*), and provide the water board with an instrument of major importance for regulating any activities that takes place on or along open water. The legal status of the statute is comparable to that of a municipal bye-law. The statute is important for sewerage too, because sewers can discharge their contents into surface waters through overflows and storm drains, and must do so in compliance with the statute.

Municipal bye-laws
A municipality has a general bye-law, which contains rules and regulations that apply to everybody within the municipal limits. Some municipalities have included do's and don'ts for areas with separated sewer systems (e.g. a car wash ban).

Since 1 January 2008, under section 10.32a of the Environmental Protection Act, municipalities have the authority to include regulations in their bye-laws controlling the discharge of rainwater and groundwater. This can be important for areas with a high ratio of disconnected impervious surfaces. Bye-laws can also include a termination date for the discharge of rainwater on wastewater sewers (mixed sewerage).

A municipality can establish a 'connection statute' for sewer connections of residential and commercial premises. See the module on sewer connection of the Urban Drainage Guideline (*Leidraad Riolering*).

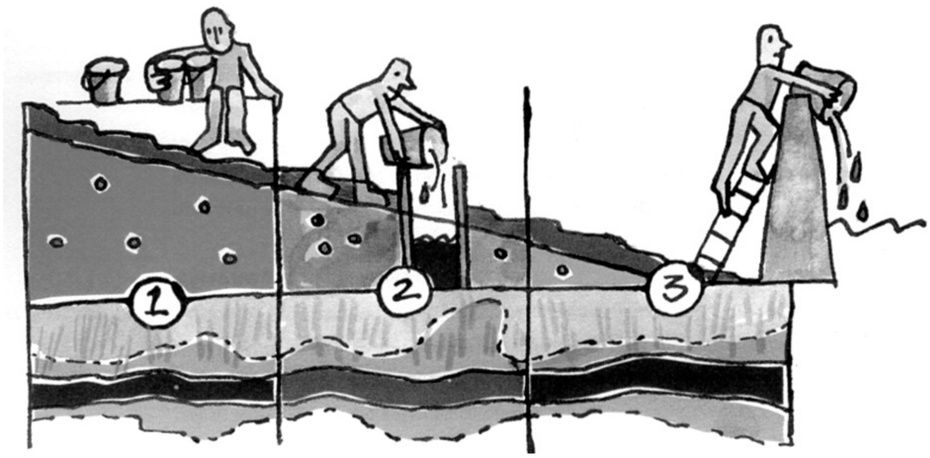
The municipal building code contains provisions regarding the presence of sewerage in buildings.

ASSIGNMENT
Look up the statutes of your home town and find out what they have to say with regard to sewerage.

Finally, a municipality can have a sewerage tax statute based on section 229 of the Municipalities Act (until 1 January 2010) or section 228a of the Municipalities Act (from 1 January 2008). This statute states who must pay sewerage tax, and how much.

3.2.2 Policy and plans
In 1995, river waters rose to dangerous levels as the result of heavy rainfall and very rapid drainage of the precipitation extremes. Large areas of the country had to be evacuated. Clearly, water management in the Netherlands left something to be desired, and plans for the future needed to include a more natural and resilient water system (water management for the 21st century). This led to the view that precipitation should first be retained, then stored, and disposed of only as a last resort. The resulting delayed drainage of rainfall ensures that precipitation extremes are attenuated.

Figure 3.3 Retention – Storage – Disposal



National Water Administration Agreement
In 2003, a National Water Administration Agreement (*Nationaal Bestuursakkoord Water*) was concluded between the national government, the Interprovincial Consultation Cooperative (*Samenwerkingsverband Interprovinciaal Overleg*), the Association of Netherlands Municipalities (*Vereniging van Nederlandse Gemeenten*) and the Union of Water Boards (*Unie van Waterschappen, UvW*).

In the National Water Administration Agreement the various authorities have laid down the proposed method, means, and time span for collectively addressing the main water issues for the Netherlands in the 21st century.

The purpose of the National Water Administration Agreement is to ensure that the Dutch water system will be in order by 2015, and that it will be kept in order for the years to come, while anticipating changing conditions, including the expected climate change, rising sea levels, subsidence, and increase of impervious surface areas.

Opening sentences of the National Water Administration Agreement:
"Structural changes are taking place in the nature and scope of the national water issues. Climate changes, rising sea levels, subsidence, and urbanisation require a new approach to water management. Therefore the national government, the Interprovincial Consultation Cooperative, the Union of Water Boards, and the Association of Netherlands Municipalities signed the Water Policy Initiative for the 21st Century (*Startovereenkomst Waterbeleid 21e eeuw*) in February 2001, thus taking the first step towards realising the required collaborative effort. Two years later the results of this collaboration and of the growing knowledge and insight have been collected in this National Water Executive Agreement, hereinafter referred to as National Water Administration Agreement".

Concluding sentences
Finally,
"With the conclusion of this National Water Administration Agreement, the signing parties emphasise the importance of a joint and integrated approach to water-related issues, and of providing additional space for water. This National Water Administration Agreement provides a major contribution towards awareness of the causes, the scope, and the urgency of these water-related issues. The parties have every confidence that the execution of this agreement will be taken up with due dispatch. The signing of this agreement is a major step towards a country dat lives with water!"

From a sewerage point of view, the Urban Water Task (Stedelijke Wateropgave) is of special importance, as it focuses on the prevention of water problems caused by such factors as limited drainage.

Section 4 Urban Water Task (Stedelijke Wateropgave)
Water can become a source of nuisance in the form of surface water overflowing its boundaries, as the result of impaired drainage caused by impervious surfaces, and due to rising water tables. The parties acknowledge the need to take stock of these phenomena:

- Before mid-2006, municipalities and water boards will draw up municipal water plans in consultation with the provincial authorities (including the basic sewerage effort, any possible optimisations, and any groundwater issues), insofar as this is deemed necessary by the parties from a water nuisance issue point of view. The parties shall take into account the claims for space resulting from the application of (labour) standards, and shall indicate the relationship with the partial catchment areas. The Union of Water Boards and the Association of Netherlands Municipalities will draw up a format.
- In 2003, the Integrated Water Management Committee (*Commissie Integraal Waterbeheer, CIW*) will prepare a recommendation for the division of responsibilities and authorities with regard to groundwater. The national government will include this recommendation when drafting the relevant legislation. In 2005 at the latest, the Association of Netherlands Municipalities and the Union of Water Boards will define administrative ground rules with regard to addressing urban groundwater issues.

ASSIGNMENT
Does your municipality have a municipal water plan, and if so, which issues does it address?

Section 4 of the National Water Administration Agreement on the Urban Water Task refers to the optional drafting of Water Plans that also address the performance of sewerage. Section 16, on communication, contains the following agreement:

> "Provinces, municipalities, water boards, and the national government will endeavour to adequately inform the population and businesses about the options for limiting water problems as a result of inundation by surface water, rainwater, sewage, or groundwater, about their expected contributions, about the existing damage claim options, and about the respective responsibilities of the population, businesses, and the authorities. In terms of organisation, the aim is to have a single point of address per region."

Re-evaluation of the rainwater policy of the Ministry of Public Housing, Spatial Planning, and the Environment

The Parliamentary records no. 29866 (see the official publications at www.overheid.nl (Dutch text only) contain the text of the letter about the re-evaluation of the rainwater policy which was sent to parliament on 21 June 2004. This policy letter lists the four corner stones on which the new rainwater policy is founded:

1. Start at the source: preventing pollution of rainwater.
2. Retention and storage of rainwater.
3. Separate disposal of rainwater and wastewater.
4. Integrated balancing of solutions at local levels.

In addition to these corner stones, three administrative principles are listed:

1. Efficiency of measures.
2. Clear definition of the responsibilities of the various parties.
3. The municipality is in control.

Water Chain Administration Agreement

In July 2007 the Water Chain Administration Agreement (*Bestuursakkoord Waterketen*) was concluded. This agreement contains arrangements that result in the improvement and further promotion of the bottom-up collaboration between municipalities (sewerage management), drinking water companies, and water boards (wastewater treatment). The intended result of these arrangements is to increase the efficiency and transparency of the execution of the respective tasks. The administration agreement acknowledges that additional taxation will be inevitable, in particular to meet the need for investments to reduce the risk of water problems and to improve the water quality. However, the joint aim should be on to minimise any additional taxation (i.e. reduce additional cost) by improving efficiency. A cost saving of 10-20% over a period of ten years should be feasible.

Plans

Sewerage forms a part of the municipal infrastructure and consequently, of the municipal environment.

A great number of plans exist for the policy fields of water, spatial planning, and environmental protection. Some of these plans have been incorporated in legislation. In addition the day-to-day practice uses a variety of voluntary plans and memos. The following table lists the main types of plan. A number of the 'plans' in this table that have a particular import on sewerage (shown in italics) will be discussed in more detail.

Municipal Sewerage Plan

The Municipal Sewerage Plan is mandatory under the Environmental Protection Act.

Table 3.2 Types of Plan for the policy fields of spatial planning, water management, and environmental protection

Plan type →	Spatial planning	Water management	Environmental protection
National strategic	Spatial Planning Memorandum (*Nota Ruimtelijke Ordening*); Planning Policy Decision (*Planologische Kernbeslissing, PKB*)	Water management memorandum (*Nota waterhuishouding*)	National environmental policy plan (*Nationaal Milieubeleidsplan*)
National Operational		National waters management plan (*Beheersplan Rijkswateren*)	National environmental programme (*Nationaal Milieuprogramma*)
Provincial Strategic	Region plan (*Streekplan*)	Provincial water management plan (*Provinciaal Waterhuis-houdingsplan*)	Provincial environmental policy plan (*Provinciaal Milieubeleidsplan*)
Provincial Operational		Groundwater plan (*Grondwaterplan*)	Provincial environmental programme; Groundwater protection plan (*Provinciaal milieuprogramma; Grond-waterbeschermingsplan*)
Regional Strategic (water board)		Catchment area plan; Water management plan; Water system vision; Water chain vision (*Deel-stroomgebiedplan; Water-beheersplan; Watersys-teemvisie; Waterketenvisie*)	
Regional Operational (water board)		Wastewater system optimisation (*Optimalisatie Afvalwatersysteem, OAS*)	
Municipal Strategic	Structure plan; Zoning scheme (*Structuurplan*; *Bestemmingsplan*)	Municipal sewerage plan; Water plan (*Gemeentelijk Rioleringsplan; Waterplan*)	Municipal environmental policy plan (*Gemeentelijk milieubeleidsplan*)
Municipal Operational		Outlying areas sewerage plan; Disconnection plan; Disconnection opportunities map; Basic sewerage plan; Dredging plan; Wastewater agreement (*Rioleringsplan buitengebied; Afkoppelplan; Afkoppelkansenkaart; Basis-rioleringsplan; Baggerplan; afvalwaterakkoord*)	

When the Plan became mandatory in 1993, the Urban Drainage Guideline included a sample list of contents with a sample Municipal Sewerage Plan. Since all but a few municipalities have by now drawn up a Municipal Sewerage Plan on one or more occasions, the Municipal Sewerage Plan is on its way to becoming a genuine municipal plan. Consequently, the latest amendment to the Municipal Sewerage Plan module in the Urban Drainage Guideline no longer includes a sample list of contents. Instead, the focus is now on the functions that planning (and therefore a Municipal Sewerage Plan) can have.

The following functions are listed:
1. The framework for implementing and maintaining sewerage: what will the municipality do in the coming planning period?
2. Internal coordination of sewerage policy with other municipal policy fields and tasks (building inspection, environment, public space, finances).
3. External coordination of the sewerage policy with other authorities (water authority, provincial executive).
4. Continuity in sewerage policy in general, and progress monitoring in particular: how close have we come to achieving our objectives?

Environmental Protection Act § 4.8 — The Municipal Sewerage Plan (from 1 January 2008)

Section 4.22
1. The local council defines a Municipal Sewerage Plan for a period set by the council itself.
2. The plan shall comprise at least:
   a. a list of the facilities provided by the municipality for the collection and transport of urban wastewater as referred to in section 10.33, as well as for the collection and subsequent processing of rainwater as referred to in section 9a of the Water management act, and measures to prevent or limit as much as possible any ongoing adverse effects of the groundwater table on the use allocated to the land, as referred to in section 9b of the above-mentioned act, and an indication of the time by which said facilities are expected to be due for replacement;
   b. a list of the facilities as referred to sub a to be constructed or replaced during the period covered by the plan;
   c. a list of the manners in which the facilities referred to sub a and b are, or will be, maintained;
   d. the impact on the environment of the current facilities as referred to sub a and of the activities announced in the plan;
   e. a list of the financial consequences of the activities announced in the plan.
3. If the municipality is subject to a municipal Environmental Policy Plan, the local council shall take said plan into account when drawing up a municipal Sewerage Plan.

Section 4.23
1. The municipal Sewerage Plan shall be prepared by the mayor and aldermen, who in doing so will consult at least:
   a. the provincial executive;
   b. the management of the treatment plants to which the collected wastewater is to be transported, and
   c. the management of the surface waters into which the collected water is to be discharged.
2. As soon as the plan has been accepted, the mayor and aldermen will inform the Minister and the parties listed sub a to c by sending the plan to them.
3. The mayor and aldermen will announce the plan's acceptance in one or more daily newspapers or newsletters that are distributed within the municipality, indicating the method by which the contents of the plan may be obtained.

The Municipal Sewerage Plan reflects the sewerage policy for the plan period (which is set by the local council). The description follows the Code of Practice for Sewer Management in the Netherlands (*Nederlandse Praktijkrichtlijn Buitenriolering Beheer*, NPR 3220, see section 3.2.3). This entails that the plan must describe among other things:

- the desired situation with regard to sewerage (what is the purpose of the sewers, and what are the resulting requirements?);
- the present extent, condition, and performance of the sewerage (to what extent are the objectives met as matters now stand?);
- what needs to be done in order to achieve the objectives;
- what it will cost (what are the means required to achieve the objectives?).

ASSIGNMENT
In your own municipality, ask for a copy of the Municipal Sewerage Plan and read it. Can you find the answers to the questions in the text above?

In order to gain an impression of what a Municipal Sewerage Plan entails, a sample list of contents of a Municipal Sewerage Plan is included below.

Summary

1 Introduction
- 1.1 Rationale
- 1.2 Validity
- 1.3 Procedures
- 1.4 Reading guide and layout information

2 Evaluation

3 Desired situation
- 3.1 Introduction
- 3.2 Environmental survey and relationship with other plans
- 3.3 Urban wastewater, rainwater, and groundwater policies
- 3.4 Targets for the plan period
- 3.5 Functional requirements and performance indicators
- 3.6 Measuring methods
- 3.7 Prerequisites for effective sewer management

4 Current situation and assessment
- 4.1 Introduction
- 4.2 Urban wastewater
  - 4.2.1 Existing unconnected buildings
  - 4.2.2 Disposal and treatment of urban wastewater
  - 4.2.3 List of current facilities
  - 4.2.4 Condition of the objects
  - 4.2.5 Performance of the facilities
- 4.3 Rainwater
  - 4.3.1 Processing of rainwater
  - 4.3.2 List of current facilities
  - 4.3.3 Condition of the objects
  - 4.3.4 Performance of the facilities
- 4.4 Groundwater
  - 4.4.1 Explanation of groundwater regime
  - 4.4.2 List of current facilities
  - 4.4.3 Complaints
  - 4.4.4 Problems
  - 4.4.5 Use of the facilities

5 The task in hand
- 5.1 Construction of facilities
  - 5.1.1 For existing buildings
  - 5.1.2 For new buildings
- 5.2 Management of existing facilities
  - 5.2.1 Urban wastewater
  - 5.2.2 Rainwater
  - 5.2.3 Groundwater

6 Organisation and finance
- 6.1 Human resources: the effort required
- 6.2 Financial means: the cost
- 6.3 Cost allocation

7 Conclusions and final remark

Developments in the Municipal Sewerage Plan
As a result of the Municipal Water Tasks Establishment and Funding Act, the scope of sewerage management has widened. This is reflected in the Municipal Sewerage Plan. Municipalities have until 2013 to draw up an extended Municipal Sewerage Plan that accommodates urban wastewater, runoff, and groundwater.

Water Plan
The increased interest in water (Water Management for the 21st century, National Water Administration Agreement) has resulted in an abundance of new (Urban) Water Plans. A Water Plan is used by municipalities and water boards to define their joint view on the desired development of water issues within the municipality, both in the short term (4 years) and in the longer term (more than 15 years). In some cases the provincial authorities or the water companies also take part. Unlike the Municipal Sewerage Plan, the Water Plan is not mandatory. Even so, it has been agreed in section 4 of the National Water Administration Agreement that a Water Plan will be drawn up if municipalities and water boards consider this necessary.

In 2004 the Association of Netherlands Municipalities and the Union of Water Boards published the 'Urban Water Plan Aid', which discusses such basics as purpose and contents as well as process specifics and the various subjects that can crop up (the modules cover water quantity, water quality, water in the built environment, urban groundwater, wastewater and disconnecting rainwater, and urban water management and maintenance).

According to the Aid, the purpose of a Water Plan can be any of the following.
- To achieve a joint perspective of urban water management, including the position of urban water within the urban environment (strategic function).
- To coordinate water policies within the municipality, between the municipality and the water board, and with other parties, so as to realise the Urban Water Tasks (including the WB21 and KRW policy principles) with the lowest possible cost to society (tactical function).
- To arrive at concrete agreements about ambitions, measures, their funding, and their effect on environmental planning (operational function). For this purpose, the Water Plan can include operational plans.

The finishing touch comes at the local level. The Association of Netherlands Municipalities and the Union of Water Boards consider Water Plans in the first place to be strategic documents. Achieving the lowest possible cost to society is of prime importance.

Water Plans aren't mandatory. The National Water Administration Agreement stipulates that a Water Plan needs to be drawn up only if the parties involved considered it necessary, at least from a water issue point of view. A Water Plan may also include agreements about the way rainwater is to be handled within the urban confines. Since some of the agreements can affect sewerage, these will have to be included in the Municipal Sewerage Plan.

Basic Sewerage Plan
According to the NEN 3300 standard, 'Drains and sewers outside Buildings – terms and definitions' (*Buitenriolering – termen en definities*) a Basic Sewerage Plan is a document drawn up for a permit application (drawing, explanation, and calculation) describing the current situation of the sewerage and the proposed improvements". In many cases the document also describes a future situation. The formal foundation of the Basic Sewerage Plan lies in the Surface waters pollution act, which states that a permit is required for the discharge into surface water, and that the permit may be subject to special conditions. In order to obtain such a permit a municipality must draw up a Basic Sewerage Plan, which is an important factor in getting to grips with the system's hydraulic and environmental performance.

There is no fixed format, but the document should include:
- an assessment framework;
- a description of the current situation;
- measures for improvement;
- a description of the performance after improvement.

In addition, individual water boards often include additional requirements such as:
- pumping capacities now and in 25 years;
- prognosis of population and business numbers;
- wastewater quantities to be disposed of in the future.

A Basic Sewerage Plan module has been available in the Urban Drainage Guideline since 2008 (see also section 3.2.4).

The Basic Sewerage Plan can include measures for improving sewerage performance. These measures also appear in the Municipal Sewerage Plan, which may include the research effort, 'drawing up a Basic Sewerage Plan'. With the advent of the Water Act the overflow permits will probably be replaced with general regulations. The Basic Sewerage Plan will remain necessary to demonstrate that the general regulations are observed.

Disconnection Plan / Disconnection Opportunities Map
Disconnection involves correcting a situation in which precipitation falling onto impervious surfaces (roofs, roads, pavements) is carried off into a mixed sewer system. As a result of disconnection less clean water is conveyed to the wastewater treatment plant, and less water will overflow into surface water.

Disconnection Plans aren't mandatory. The purpose of the plan is to disconnect rainwater and any pumped-up groundwater from the wastewater treatment plant. A Disconnection Plan describes the ins and outs of disconnection. This means that it addresses the pollution of rainwater by diffuse (scattered) sources and the discharge options for the disconnected water, but also any practical aspects and the means of promoting the population's participation and involvement.

Disconnection Opportunities Maps have no legal status either. They are drawings that indicate in which parts of the municipality disconnection may be effected in a more or less simple manner, taking into account the geological conditions and the layout of the environment.

Wastewater System Optimisation Study
A Wastewater System Optimisation Study (*Optimalisatie Afvalwatersysteem, OAS*) isn't required either. In a Wastewater System Optimisation Study the water board (which manages the wastewater treatment plant), together with the municipality (or several municipalities), searches for a sensible way to set up the sewer system and the wastewater treatment plant at the lowest possible cost. The target area of the study is the catchment area of the wastewater treatment plant.

Optimising a part of the water chain, i.e. the wastewater system, has a double purpose:
- To achieve the best possible wastewater system at the lowest possible cost to society.
- To minimise the discharge of blackwater into surface water from the municipal sewer overflows and the discharge from the waste water plant.

A Wastewater System Optimisation Study can investigate any of the following.
- Whether centralised control using a system of adjustable valves can optimise the use of the sewer system's holding capacity.
- Whether rainwater from impervious surfaces can be disconnected, which reduces the quantity of rainwater entering the system and obviates the need for treating it.
- Whether the pumping regime must be modified, so in separated sewer systems the rainwater does not mix with foul water, and instead is conveyed directly to surface water.
- Whether any opportunities for storage exist, so the wastewater can be temporarily stored and rerouted to the wastewater treatment plant in order to accommodate a peak inflow.

Wastewater Agreement
"The Wastewater Agreement is a process that produces a concrete result with a firm administrative basis, which lists the arrangements regarding the wastewater chain. The agreement is not mandatory yet. If the Wastewater Agreement results in new policies in addition to the mandatory plans (i.e. the Municipal Sewerage Plan and the water board's water management plan), like the mandatory plans such policies must be arrived at locally in a democratic fashion (i.e. approved by the municipal authorities)." (Association of Netherlands Municipalities / Union of Water Boards Wastewater Agreement Aid).

A Wastewater Agreement often is the administrative implementation of a Wastewater System Optimisation Study. It does not have any legal status, but is is mentioned in the Government Perspective on the Water Chain (*Rijksvisie op de Waterketen*) as an important instrument for coordinating the water system and the water chain.

3.2.3 Standardisation
Sewerage in the Netherlands is subject to a number of standards, which are published by the Netherlands Standardisation Institute (*Nederlands Normalisatie Instituut, NEN*). Here is a list of the standards for exterior sewerage that have been developed or updated in the past few years:

NEN 3300 – Drains and sewers outside buildings: terms and definitions (*Buitenriolering: termen en definities*). This standard contains a list of exterior sewerage terms and their definitions.

NEN-EN 13508-1 and 2: 2003 nl, Drains and sewers outside buildings: condition of drains and sewers. Part 1: General requirements, and part 2: Visual inspection coding system (*Toestand van de buitenriolering. Deel 1: Algemene eisen en deel 2: Coderingssysteem bij visuele inspectie*). This standard regulates the coding of the observations made during an inspection.

NEN 3398: 2004 nl, Drains and sewers outside buildings: Inspection and condition assessment of objects (*Buitenriolering: onderzoek en toestandsbeoordeling van objecten*). This standard sets requirements for sewer inspections and for assessing the condition of sewer components.

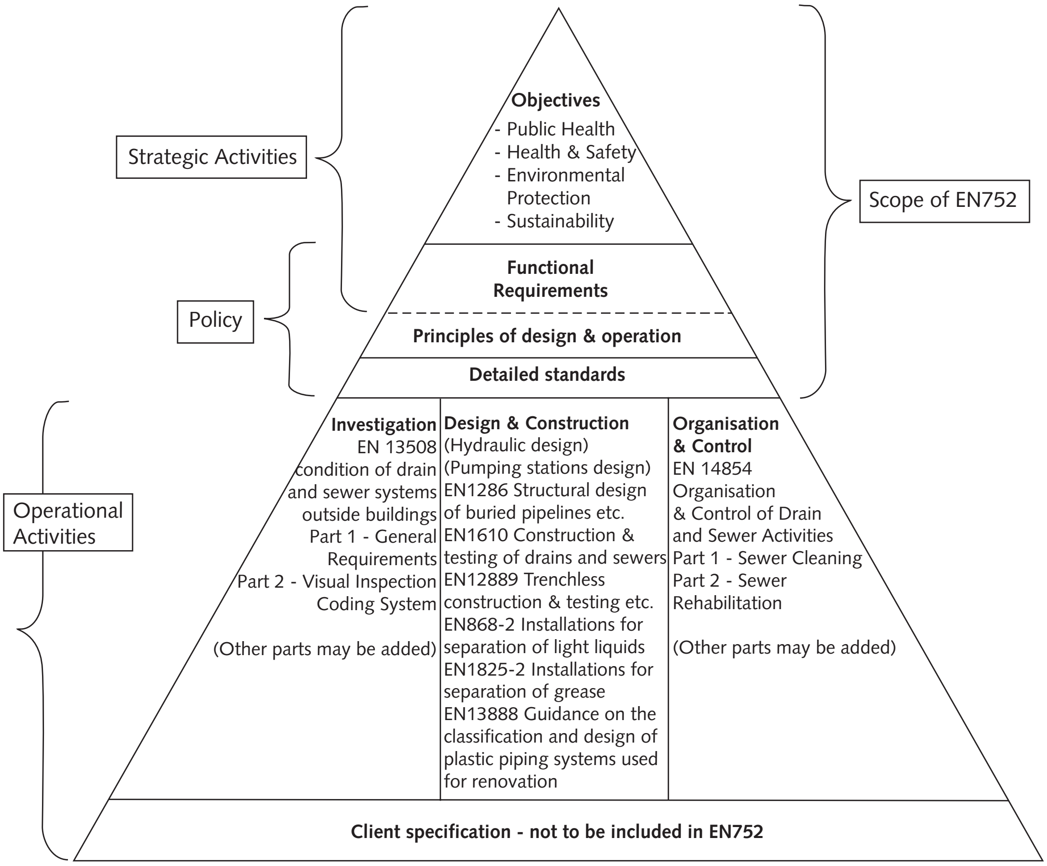
NEN 3399: 2004 nl, Drains and sewers outside buildings: Classification system for visual inspection of objects (*Buitenriolering: classificatiesysteem bij visuele inspectie van objecten*). This standard stipulates which codes from NEN-EN 13508 apply to the Dutch situation, and which do not. This is important, as it ensures that inspectors all speak the same language.
Regulations regarding the disposal of wastewater and rainwater in buildings are included in the Building Resolution and the municipal building code.

In 1987 the sewerage industry introduced a code of practice (NPR 3220) for sewerage management. The code was updated in 1994, and regulates municipal sewerage management, instructs the manager how to manage the sewer system and how to set up the management, which processes to follow, which plans need to be made, and how to adopt resolutions. The code also includes instructions for proper data management as well as the prerequisites for management system software. The Urban Drainage Guideline is partly based on this code, as are the Dutch Civil Engineering Rationalisation (*Rationalisering Automatisering Water- en wegenbouw, RAW*) system and other Dutch standards. NPR 3220 provides a framework for managing sewer systems.

The European standard EN 752 for drains and sewers outside buildings has existed since the end of the 1990s. This standard, which came in seven volumes, encompasses the scope of NPR 3220. Nevertheless the standard is practically unknown to the legislative powers, sewerage administrators, and engineering companies, let alone that it is used as a basis for design practice. EN 752 also had little in common with the way things operate in this country, which is why the Netherlands took the initiative to adapt the standard to the Dutch situation.
NEN-EN 752 is a standard, not a code of practice, and like NPR 3220 provides a framework: in principle it covers all sewerage standards in the Netherlands and Europe. This means that the standard far exceeds the current NPR 3220 in scope, which is why it is important.

An important mental framework in the standard is expressed in the so-called pyramid diagram.

Figure 3.5 NEN-EN 752 mental framework



The diagram outlines the various sewerage activities and also indicates that the basis of management is to work with objectives, functional requirements, and performance criteria. Chapter 7 discusses this in more detail.

3.2.4 Urban Drainage Guideline

The Urban Drainage Guideline (*Leidraad Riolering*) is a sizeable volume containing lots of information about sewerage management. The Urban Drainage Guideline came into existence in 1991 in the government memorandum, 'Sewerage – Towards an environmentally protective collection and transport system (*Riolering – Naar een in het milieubeheer functioneel inzamel- en transportsysteem*) (Session year 1991-1992, Parliamentary records 19826, no. 18). This is the policy memorandum that lay at the basis of making the Municipal Sewerage Plan mandatory. The proposed procedure accompanying the memorandum promised to deliver the Guideline as an aid for the municipalities.

The purpose of the Guideline is to harmonise the technical, financial, and organisational aspects of sewerage management in a broad sense, and to achieve coordination for current issues. This means that the Guideline should be seen as a consensus guideline.

The Guideline's contents primarily address the role, tasks, and responsibilities of municipalities and water management authorities on an operational level.

The Urban Drainage Guideline consist of four main categories:
A: Administrative and Legal Aspects
B: Design Principles
C: Operational Management
D: Means

The four categories provide an initial structure for arranging the subjects covered by the modules. Preceding the module texts, a reading guide has been included. The Guideline ends with a cumulative keyword index. Both are useful aids for looking up a subject.

The Urban Drainage Guideline is published by the RIONED Foundation, see also www.riool.net.

3.3 Technical developments
In addition to the developments in context and policy, technical developments also affect the practice of sewerage. Sewerage is the subject of much research. Ongoing research is necessary because many of the processes that occur inside sewer systems have yet to be analysed. Since sewerage management puts a heavy financial burden on society, ongoing research is also necessary in order to ensure that the money is spent as efficiently as possible. Sewer systems have been the subject of measurements for some years now. New developments will be initiated on the basis of the results obtained from these measurements and their subsequent analysis.

The CAPWAT research should also be mentioned. As it turns out, many pressurised pipelines do not achieve their design flow capacity due to increased resistance within the system. This can be caused by a number of things. An extensive survey has revealed that trapped air and gas bubbles account for a major proportion of these extra losses. The formulas currently in use for gas bubbles in transport pipelines are limited in their application scope, and do not provide answers to a number of design questions. The CAPWAT research programme was launched in 2003 to investigate the behaviour of gas bubbles, their effect on transport capacity, and the resulting loss of energy, with the aim of defining improved design regulations and improving operational efficiency.

The developments in the material domain are also important, since new materials often result in new applications. The introduction of plastic pipeline components for example, made it possible to construct pressurised sewer systems.

Figure 3.5 Urine-separating lavatory

Another important development is urine separation (figure 3.5). Urine contains the great majority of hormone-disrupting chemicals and medication residue. The separate collection of urine and the subsequent treatment of this wastewater flow drastically reduces the environmental impact from harmful substances.

Developments in the field of ICT are also important. Whereas in days gone by sewerage had to be laid out using traditional surveying methods, these days GPS applications are the norm. GIS applications are also on the advance in the world of sewerage management.

The desire to disconnect sewer systems has led to the development of a variety of disconnection products. See the disconnection database of the RIONED Foundation for more information.
Many technical innovations are product innovations coming from various manufacturers of sewerage components, which is why the reader is encouraged to refer to the professional literature and the websites of the manufacturers.

Self-assessment questions for chapter 3

1. Name the main effects of the expected climate developments on sewer systems in urban areas. What are the consequences in terms of environmental planning?
2. Table 3.1 shows that on average the Netherlands experience a single day (24 hours) every 10 years in which the total rainfall measures 54 mm. If the amount of rain were to increase by 20%, the 24 hour level would be 65 mm. Question: How many times was the 65 mm level reached or exceeded within 24 hours in 2008?
3. Name a number of causes for the ever increasing area of impervious surfaces within the urban regions in The Netherlands. How does this development affect sewerage?
4. The Municipal Water Tasks Establishment and Funding Act makes it possible to allocate collected sewer tax to various municipal responsibilities. Name these responsibilities. What do they entail? The municipality recovers the cost of these responsibilities from the population and businesses by imposing sewer rates. What is the difference between the current system of sewer taxation and the former system of sewer retribution that applied before the introduction of the Municipal Water Tasks Establishment and Funding Act?
5. In the National Water Administration Agreement the authorities have laid down agreements concerning the Urban Water Task. What does the Urban Water Task entail? The Water Plan is a type of plan in which the Urban Water Task may be developed in further detail. Name some of the water policies that can be included in an urban Water Plan. Is the urban Water Plan a mandatory type of plan, just like the Municipal Sewerage Plan?
6. The Municipal Sewerage Plan, is a mandatory type of plan detailing a municipality's water management responsibilities. What are the functions of the Municipal Sewerage Plan? What does an Extended Municipal Sewerage Plan entail? What are the minimum ingredients of a Municipal Sewerage Plan?
7. What is a Basic Sewerage Plan? Does a municipality still have to prepare a Basic Sewerage Plan now that the new Water act has been introduced?
8. The NEN-EN 572 standard provides a mental framework for sewerage management. Name the main elements and activities covered by the standard.
9. Which parts of sewerage management does the Urban Drainage Guideline describe?
10. What is urine separation? What is its use? At which point do you think urine separation will be the most efficient?

4 Organisation of sewerage management

This chapter discusses the organisation of sewerage management. It starts by looking at the tasks and responsibilities. Next, the objectives, functional requirements and performance criteria as touchstones for sewerage management are discussed: are we doing the right things, and are we doing them right? Section 4.3 deals with the available means for sewerage management: human resources and funding. Sewerage management is not a field on its own, and so the final sections include a short discussion of the relationship that sewerage management has with other municipal tasks and with the other components of the water chain.

4.1 Tasks and responsibilities

The Municipal Water Tasks Establishment and Funding Act gives municipalities the following responsibilities.

- The responsibility for collecting and transporting urban wastewater.
- The responsibility for efficiently collecting and processing rainwater.
- The responsibility for taking measures in the public municipal domain to prevent or limit, as much as possible, any ongoing adverse effects of the groundwater table on the intended use of the land, insofar as this is efficient and insofar as this task is not the responsibility of the water board or the provincial executive.

The responsibility for the disposal of urban wastewater has long been a task of municipalities. The rainwater task also was already being handled by municipalities, but this situation has now finally been made explicit. The groundwater task is new and will lead to additional activities in many municipalities. The municipality is responsible for the correct execution within its domain of the water tasks referred to above.

The water management authority (at the national level: *Rijkswaterstaat*, part of the Ministry of Transport; at the regional level: the water boards) is responsible for the water system (surface water and groundwater bodies) and the treatment of wastewater.

Since 2008 the municipalities have also been responsible for the discharges into surface water through sewer systems, known as indirect discharges. Until 1 January 2008 some 20 categories of these discharges came under the responsibility of the water management authority. Since 1 January 2008 the water management authority does still have a major advisory capacity, since it represents so much know-how in these matters.

Collaboration with the water board is becoming increasingly important. The Water Chain Administration Agreement stipulates that the water board and the municipality should manage the wastewater chain (sewerage plus treatment) as if it were a single system managed by a single responsible party. Section 3.5a of the future Water act will include the provision that water boards and municipalities are responsible for the necessary coordination of tasks and authorities with a view to efficient and coherent water management.

Municipalities and water boards will therefore have to make arrangements about who will be doing what, and who is authorised to carry out which tasks. This could for example be laid down in a Wastewater Agreement or in some other administrative agreement.

4.2 Efficient sewerage management

Sewerage serves a specific purpose. In 1952 this purpose was described as: "to remove the rainwater, the wastewater, and any waste materials that are harmful to the general health of humans and animals, as completely as possible from the built environment, and to transport them to locations where they are less harmful, or can be rendered harmless, and where they can be processed into useful materials if necessary (Imhoff in: *Van den Akker, J., 1952. Rioleringen, Deel I: Het ontwerpen en berekenen van een riolennet, Leiden. A.W. Sijthoff's Uitgeversmaatschappij*)". The purpose of sewerage therefore has two aspects or functions: collection and transport.

The safeguarding of public health, keeping our feet dry, and creating a healthy living environment; these are the main objectives of sewerage. In the Urban Drainage Guideline, module A1100, these have been detailed for sewerage management as laid down in the Environmental Protection Act and the Water management act since 1 January 2008.

The objectives can be described as:
1. To take care of the collection of urban wastewater.
2. To take care of the transport of urban wastewater.
3. To take care of the collection of rainwater.
4. To take care of the disposal of rainwater.
5. To ensure that the groundwater table does not impair the intended use of land.

In order to achieve these objectives, requirements must be set regarding the condition and performance of sewerage. There is no point in setting requirements unless the effect of these requirements can be measured. This means that performance criteria must be defined in combination with measuring methods. These objectives, functional requirements, and performance criteria form the basis on which the municipal administration takes long-term decisions about the appropriate sewerage policy in its Municipal Sewerage Plan.

The method of using objectives, functional requirements, and performance indicators has been standard practice in the Netherlands for almost fifteen years (and has gained wide acceptance). The same approach is maintained in the European Exterior Sewerage standard, NEN-EN752 (in draft).

Twenty years ago it had not yet become common practice to think in terms of objectives, requirements, and performance criteria. Sewerage management authorities all did their utmost, but why they did things the way they did was often impossible to explain in political circles. It was as if they were all adrift on their own, without a coastline or jetty to set out for. If you produce an accurate definition of what you are trying to reach, you can also say when you intend to be there, and what it takes to get there. In the example of the dinghies this means that you are able to say that you want to reach the jetty at such and such a time, and that to get there in time you need more rowers, or an outboard engine. There is a relationship between what you ask in terms of means and the objective you intend to achieve.

So, objectives are the descriptions of the desired (ideal) situation with regard to the condition and the performance of the facilities in relationship to the environment. This applies to all three of the municipal water tasks/responsibilities: urban wastewater, rainwater, and groundwater.

They define what objectives are to be achieved. The functional requirements define the conditions that must be met and how the facilities must perform in order to be able to achieve the defined objectives. Note that functional requirements are not the same as measures. Functional requirements

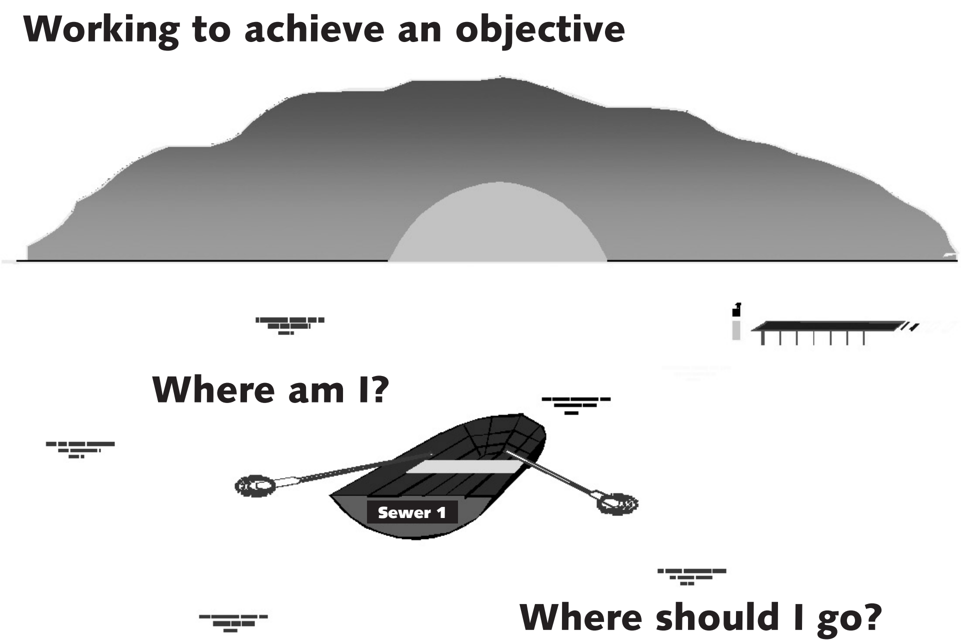


Figure 4.1 Working to achieve an objective

are generally expressed in terms of qualitative (i.e. not yet quantified) levels like ‘sufficient’, ‘acceptable’, ‘adequate’.

Performance criteria are the quantified expression of the functional requirements: what is acceptable, what is sufficient, what is adequate. They are required in order to enable us to determine whether the functional requirements have been met. Performance criteria make the functional requirements verifiable in a quantitative sense. Performance criteria are highly localised. For example, the municipality, in consultation with e.g. the water management authority, determines the performance criteria to use when it comes to emissions into surface water.

Here is an example to clarify the process:
We take the objective ‘to take care of the collection of urban wastewater’ and add a functional requirement and performance criterion.

Functional requirement: the objects (sewer pipes, manholes, etc.) must be in good order.

Performance criterion: an inspection may not reveal any damage in excess of class three.

If an inspection reveals class 4 damage, the requirement has not been met, and appropriate action must be taken.

Achieving the objectives is something that needs to be done without causing any undue impact on surface water, soil, and population. We need to collect and transport in such a manner that problems due to excess water do not occur too often, but we don’t want to discharge too much much polluted water into surface waters either.

In this way every objective can be paired with one or more functional requirements and performance criteria. This completes the framework of sewerage management.

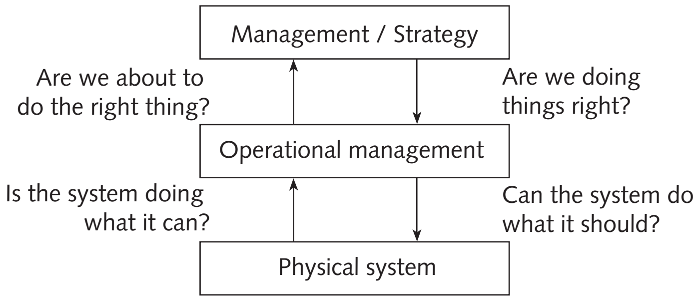


Figure 4.2 The sewerage 'figure of eight'

In addition to the objectives we also have conditions for efficient management. The sewerage management authority needs to meet these in order to be able to achieve the objectives in an appropriate manner. This include such things as:

- Sewerage management must be coordinated as closely as possible with other municipal tasks (regular consultation with other departments such as road management, parks and other public vegetation, public planning).
- Sewerage management must be coordinated as closely as possible with the tasks and responsibilities of other authorities and interested parties (regular consultation with water boards, provincial executive, housing corporations).
- The users of and the discharges into sewerage must be known (proper connection records).
- The condition and performance of sewerage must be clear (inspection once every x years, updated calculations).

It all boils down to making sure that the sewerage management authority does all the right things, and that it does them the right way.

Objectives, functional requirements, and performance criteria make this transparent and discussable. They form the link between the administration that defines a policy and the operational management that has to deal with the physical system (the sewerage).

4.3 Means in sewerage management

This section looks at which is required in the sense of human resources and funding in order to achieve efficient sewerage management on a broad scale. This is what sparks the most interest in political circles, and therefore some insight into the backgrounds will come in useful.

Buried in the Dutch soil lie some 100,000 kilometres of sewerage with a combined value of 58,000 million euros (from 'Urban Drainage Statistics 2005-2006', *Riool in cijfers 2005-2006*, RIONED Foundation). This kind of capital deserves to be properly managed!

Proper management requires the proper means, in terms of both human resources and financial means. Human resources are important, but in most municipalities the number of available staff places for sewerage management have remained the same, or worse, have decreased. Time and time again it turns out, as with the 2003 Policy evaluation for the Ministry of Public Housing, Spatial Planning, and the Environment, that the proposed activities cannot be realised according to plan due to lack of human resources (see 'National sewerage policy and realisation closer!?, Sewerage Management Policy Evaluation, Ministry of Public Housing, Spatial Planning, and the Environment', *Rijksrioleringsbeleid en realisatie dichterbij!? Beleidsevaluatie rioleringszorg, Ministerie VROM, 2003*). The situation has not visibly improved since 2003.

Added to this come the other tasks which are now being formalised under the Municipal Water Tasks Establishment and Funding Act, i.e. the responsibility for managing rainwater and taking the appropriate groundwater management measures.

Sufficient numbers of qualified staff are a prerequisite if the proposed actions of the Municipal Sewerage Plan are to be realised.

4.3.1 Human resources

The Urban Drainage Guideline of the RIONED Foundation includes the module D2000, 'Human resources aspects of municipal sewerage management' (*Personele aspecten van rioleringsbeheer*). This module is intended to be an aid for plotting the human resources aspects of everything to do with the municipal water tasks within a municipal situation. Since the module can be very helpful in calculating an initial estimate of the required human resources, we will discuss it in more detail.

Tasks and activities

The Municipal Water Tasks Establishment and Funding Act gives municipalities the following responsibilities.

- The responsibility for collecting and transporting urban wastewater;
- The responsibility for efficiently collecting and processing rainwater;
- The responsibility for taking measures in the public municipal domain to prevent or limit, as much as possible, any ongoing adverse effects of the groundwater table on the intended use of the land, insofar as this is efficient and insofar as this task is not the responsibility of the water board or the provincial executive.

The municipal water tasks can be subdivided into the five following partial tasks:

Planning
- (Extended) Municipal Sewerage Plan
- Coordination with other plans (e.g. Water Plan)
- Annual programmes

Investigation
- Inventory
- Inspections/checks
- Measurements
- Calculations

Maintenance
- Sewers/manholes
- Pumping stations/mechanical sewerage
- Infiltration facilities/local treatment
- Groundwater facilities

Measures
- Construction
- Repairs
- Rehabilitation/renovation/replacements
- Improvements

Supporting services (data management, permits, complaints, water information service)

These partial tasks constitute the framework for everything that needs to be done in terms of municipal water tasks. This enables a structured analysis to be carried out.

The partial tasks are discussed in further detail in the Urban Drainage Guideline module D2000.

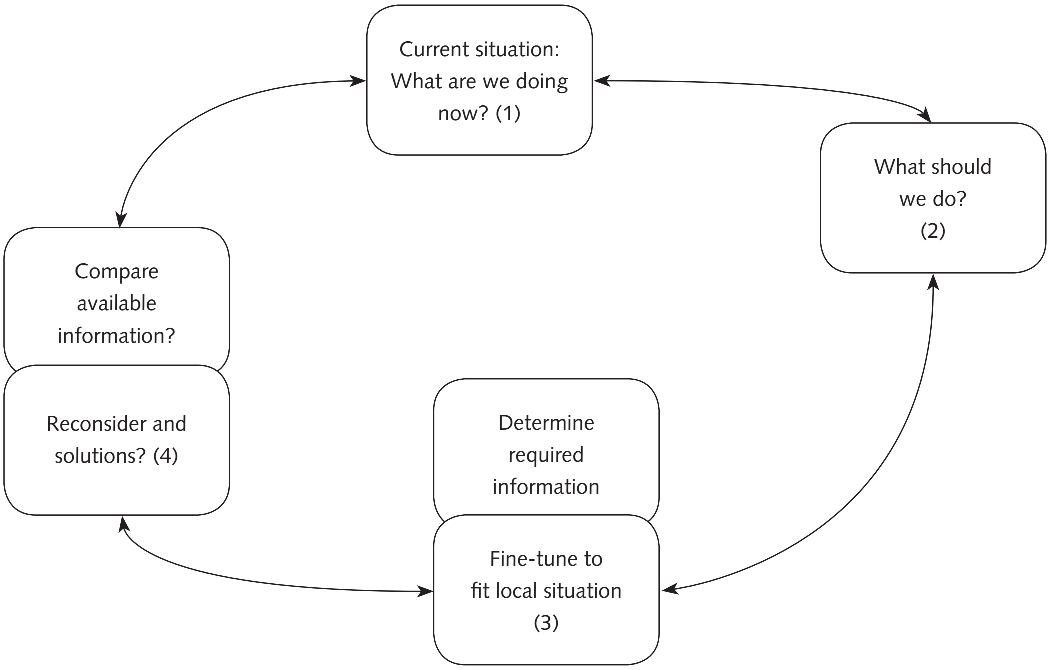
Estimating the number of required staff
The number of staff required for adequately carrying out the proposed tasks outlined in the Municipal Sewerage Plan (chapter 'The task in hand') depends on many different factors. It is therefore impractical to provide general guidelines for the number and type of staff required to carry out the municipal water tasks. Such aspects as complexity, political preferences regarding outsourcing, and the exchangeability of tasks vary between different municipalities.

Nevertheless, it is possible to give a general indication of the time required for the most common activities within the municipal water tasks. By refining these general guidelines for the local situation, each municipality can make a rough estimate of the human resources required to adequately carry out the various actions proposed in the Municipal Sewerage Plan.

The method described in this chapter is presented in more detail in the Urban Drainage Guideline module D2000. The general outline of the method follows a number of steps, which together result in a useful indication of the quantity and quality of the human resources required. Completing these steps in succession will provide structured insight into the required outlay in terms of effort.

Step 1 is an analysis of the hours spent in the current situation: who does what, and how much time do they spend doing it?
Step 2 follows from the Municipal Sewerage Plan, which states what is to be done during the planning stages.
This is followed by step 3.

Figure 4.3 Steps to determine human resources requirements



Step 3: how many people does it take?
The Urban Drainage Guideline distinguishes between three sizes of municipality, for each of which a quantitative indication is given:
- Up to 20,000 inhabitants
- Between 20,000 and 50,000 inhabitants
- Over 50,000 inhabitants

For each of the municipality sizes and different levels of outsourcing, index figures are given regarding planning, investigation, and supporting services. Maintenance has been made proportional to the current range of facilities (what do we have available?). The deployment for measures is determined on the basis of the investments included in the Municipal Sewerage Plan. The website of the RIONED Foundation, www.riool.net, includes a calculation model to help estimate the human resources required.

In the table below, which is intended for a municipality of up to 20,000 inhabitants, the columns cover the activity, the index figure for time spent, the maximum outsourcing percentage, the current outsourcing percentage in the sample municipality, and finally, the necessary time outlay, measured in days per year.

Table 4.1 Human resources calculation model for planning, investigation, and supporting services

Municipality with 20,000 inhabitants					
	Time spent in days per year	**Max. outsourcing**	**Current outsourcing**	**Time spent in days per year**	**Supervision**
Planning					
(Extended) Municipal Sewerage Plan	45	70%	70%	14	Feedback within municipality, consultation, strategy and means
Coordination and consultation	20	–	–	20	In-house task
Annual programmes	70	40%	40%	42	Consultation and coordination with other management authorities, annual budgeting
Investigation					
Inventory	5	–	–	5	In-house task
Inspections/checks	90	80%	80%	18	Planning, outsourcing, financial matters
Measurements	30	50%	50%	15	Processing and accounting
Functional supervision (calculations, disconnection plans, waste-water system optimisation study)	20	–	–	20	In-house task
Supporting services					
Processing revision data	10	90%	90%	1	
Permits and related information	15	–	–	15	In-house task
Analysing and processing complaints	20	–	–	20	In-house task
			Total time spent	170	Days per year
			fte (1 fte = 175 days per year)	0.97	

As can be seen, in this situation almost 1 fte is required to satisfactorily perform these partial tasks (with outsourcing).

As far as maintenance goes, this is determined by the number of facilities (for urban wastewater, rainwater, and groundwater). The local situation can be quantified in terms of sewerage length, the number of pumping stations, the number of pressurised sewerage pumping units, and the number of facilities for rainwater and groundwater. Again the percentage of outsourced work can be indicated.

No national index figures are currently available for groundwater facilities (including drainage), so the current time spent on this task in the local situation (in days per year) can simply be entered here. Below are the completed figures for our sample municipality of 20,000 inhabitants.

Table 4.2 Human resources calculation model for maintenance

Type of system	Length in km	No. of facilities	Remarks
Combined	60		
Separated	5		Foul sewer + storm drain!
Improved separated	5		Foul sewer + storm drain!
No. of pumping stations		3	
No. of pressurised sewerage pumps		45	
No. of special rainwater facilities		1	No. of swales, no. of underground retention facilities, permeable paving, etc.
Drainage	0		

Component	Days per year	Outsourcing	Municipality days
Sewers/manholes	229	10%	206
Pumping stations/mechanical sewerage	150	50%	75
Infiltration facilities/local treatment	6	0%	6
Drainage	0	0%	0
Planning and supervision	15		15
Total	400		302

Component	fte	Outsourcing	Municipality fte
Sewers/manholes	1.3	10%	1.2
Pumping stations/mechanical sewerage	0.9	50%	0.4
Infiltration facilities/local treatment	0.0	0%	0.0
Drainage	0.0	0%	0.0
Planning and supervision	0.1		0.1
Total	2.3		1.7

A useful estimate of the maintenance effort requires that the numbers of available facilities used are correct.

Measures
Construction, replacement, or improvement must be prepared and supervised. This is entered in terms of a percentage of the cost price (preparation and supervision). Based on hourly or daily rates for staff, the required human resources can then be calculated.

Example
For the next few years, the plans include an investment with a contract price of 1 million euros. The normal preparation and supervision percentage within the municipality is 12%. This means that € 120,000 can or will be spent on preparation and supervision. Assuming a daily rate of € 600 a staff effort of 200 days will be required. Based on a certain outsourcing percentage, the remaining municipal effort can then be calculated. In this way all the investments included in the Municipal Sewerage Plan can be allotted their respective human resources requirement.
The table below includes an example of this.

Table 4.3 Human resources calculation model for capital works

	'Bare' cost (euro)	Preparation and supervision	Staff cost (euro)	max. outsourcing	Current outsourcing	Working days
Construction						
New		12%	–	60%	35%	–
Existing		15%	–	60%	10%	–
Drainage	10,000	10%	1,000	60%	0%	3
Repairs	80,000	15%	12,000	60%	50%	15
Updating	350,000	12%	42,000	60%	35%	68
Replacement	1,400,000	12%	168,000	60%	10%	378
Improvement		15%	–	60%	20%	–
					Total	**464**
					fte (1 fte = 175 days per year)	**2.7**

Hourly rates of staff: 40 euros per hour.

What kind of staff is needed?
Adequate staffing not only depends on the number of people, but also on their knowledge and skills. The Urban Drainage Guideline module D2000 distinguishes between three levels of training: Academic, Higher Professional Education, and Intermediate Professional Education. Additional training (specific to the sewerage field) is often required. In some cases experience can partly compensate for a lack of formal training. This is indicated by means of a plus sign (e.g. Acad./ HPE+ for preparing a Municipal Sewerage Plan).

The end result of the calculations will be a complete list of the required staff outlay, which can then be compared with the current staff numbers. The resulting differences can be solved in a number of different ways (assuming a shortage of staff):
- Hiring more staff
- Hiring temporary staff
- Training current staff
- Outsourcing tasks/activities
- Increasing collaboration
- Cancelling certain tasks/activities

Before the most suitable solution can be found, the local factors will have to be investigated in detail. This is step 4 in Figure 4.3. This step is required because in the first place the Urban Drainage Guideline module D2000 is based on a nationally average situation, and in the second place because managers and administrators will require a properly substantiated case if the solution ever is to be implemented.

The number of staff required will be different for a compact municipality with a single urban centre, or for a municipality with twelve different centres and several outlying areas served by pressurised sewer systems. The level of ambition can also vary between municipalities, as can the availability of adequate data and organisational facilities.

4.3.2 Financial means

The Municipal Sewerage Plan lists the means required for implementing the proposed strategy, covering both financial and human resources.

With regard to financial resources, the 'Organisation and funding' section of the Municipal Sewerage Plan states how the expenses and returns related to sewerage management will (eventually) be balanced (see the Urban Drainage Guideline module A1050). An important item in this respect is the Budgeting and Accounting of Provinces and Municipalities Resolution (*Besluit Begroting and Verantwoording Provincies and Gemeenten*), Bulletin of Acts, Orders and Decrees 27-2003. This resolution defines what a budget should look like.

The first step is to prepare a long-term list of all the costs related to sewerage management. The previous chapter discusses the issues that play a role in this. On one side there are the expenses, while on the other side there are the returns.

The long-term cost list forms the basis for the cost-recovery section in the Municipal Sewerage Plan. It starts by explaining what comes under cost, and what comes under expenses.

Expenses, cost, and types of cost

Although in day-to-day parlance the terms cost and expenses are often used indiscriminately, there is a marked distinction.

Expenses are amounts that are paid in exchange for a product or a service at the time the product is supplied or the service is rendered.

Costs are amounts spent on certain items over a certain period of time. To calculate costs, amounts already paid and amounts remaining to be paid for certain products or services are allocated to the period or periods to which they are related, and marked down as (annual) costs (capital costs).

ASSIGNMENT

What are the costs for the years 2 – 5?

Answer: € 232,000, € 224,000, € 216,000, and € 208,000.

For example, consider the purchase of a house. The expense is the amount paid to the person selling the house, say € 200,000. The costs are formed by the (monthly) mortgage payments to the bank that supplied the money, and could amount to € 1,100 per month for 30 years.

Here is an example from the field of sewerage. A municipality needs to replace a sewage pumping station. The expense is 1 million euros. The municipality borrows the money from the Dutch National Bank at an interest rate of 4%, to be paid back over a period of five years. The cost for the first year is € 240,000.

Investment expenses

A major part of the effort required to carry out the municipal water tasks is related to the construction, replacement, and improvement of sewers, pumping stations and other facilities. The expenses for these activities are referred to as investment expenses. The investment expenses are then converted into investment costs, which are then entered in the budget; see the example above.

It should be noted that new construction work is usually paid for by the development returns. The price of land includes an amount to cover the construction of sewerage. This means that these investments are immediately paid for, so they do not have to be converted into capital costs.

Maintenance costs
The maintenance of a sewerage system will consist mainly of cleaning the sewers and keeping the pumps and pumping stations in running order. These are mostly annual costs that tend to remain more or less constant in the municipal context. Certain major maintenance works may be marked down as replacement investments, and these are treated in the financially appropriate manner.

Provision and reserve
A provision is a future commitment that can be foreseen, but will not require the necessary outlay in expenses until some time ahead. Each year a certain amount is saved to enable the expense to be paid in the future.

A reserve is more like a general buffer to cover unforeseen risks. A reserve is the result of what happens in a certain year. If a construction job turns out to be cheaper than estimated, you are left with money to spare. This money could then be added to a reserve fund.

Direct and indirect costs
Direct costs are costs for activities that are directly related to the tasks listed in section 228a of the Municipalities Act (see text frame).

Section 228a

1. Under the name sewerage tax a tax can be levied to fight the cost to the municipality of:
   a. the collection and transport of domestic wastewater and industrial wastewater, as well as the treatment of domestic wastewater, and
   b. the collection of rainwater and the disposal of the collected rainwater, as well as the taking of measures in order to prevent or limit, as much as possible, any ongoing adverse effects of the groundwater table on the intended use of the land.
2. Regarding the costs referred to in the first subsection, parts a and b, two separate taxes may be levied.
3. The costs referred to in the first subsection include the sales tax that under the VAT compensation fund act (Wet op het BTW-compensatiefonds) gives entitlement to a contribution from said fund.

Direct sewerage costs include:
- capital cost of investments;
- wages of the civil servants charged with sewerage management;
- costs of maintenance materials and equipment;
- implementation costs resulting from raising the sewerage tax.

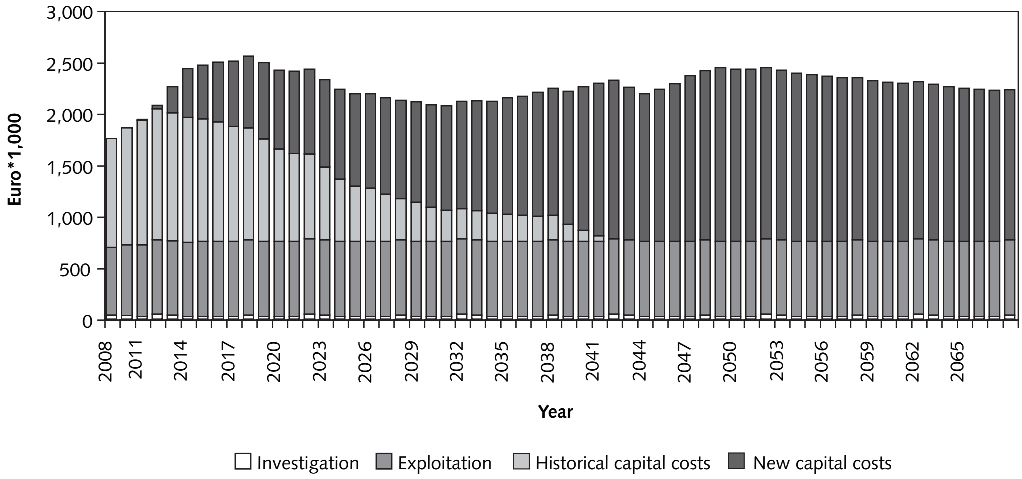
Indirect costs are costs for activities that are indirectly related to the wider range of sewerage tasks. A part of these costs is allocated to sewerage management.

Indirect sewerage costs include:
- part of the wages of policy-making civil servants;
- part of the accounting costs;
- part of the accommodation costs of the municipality;
- part of the costs for such items as postage, document reproduction, literature, etc.;
- part of the costs for such activities as road-sweeping, unblocking drains, etc.

Long-Term Cost Perspective

The final result will be a long-term perspective of all the costs bearing on the budget.
It should be noted that the planning period (usually about five years) is most important because that is the time for which the actual resolutions are made. Since sewerage lasts for 40 – 60 year, the long-term perspective often covers that period.
The long-term perspective completes the first cornerstone of the cost-recovery section for the Municipal Sewerage Plan.

Figure 4.4 Long-term cost perspective



Returns

The second cornerstone of the cost-recovery section consists of the long-term perspective of the expected returns. A number of different sources of income are available to balance the planned costs of sewerage management with the required returns. By combining the sources of income, a list can be created of all the returns that will be used to cover the costs.

Covering the costs in this context means that over the period under consideration the total of the returns is in balance with the total of the costs.

Possible sources of income are the general funds of a municipality, third-party subsidies, municipal improvement benefits, third-party contributions, reserves or provisions, rates, connection fees, and of course the sewerage tax under section 228a of the Municipalities Act. The current sewerage tax is based on section 229 of the same act.

In the following we will take a closer look at the most common source of income, the sewerage tax.

It should be noted that water boards charge separate fees to cover the treatment of wastewater, for flood protection measures, and for improving water quality.

Sewerage Tax

The legal basis of sewerage tax

The new-style sewerage tax is a periodical municipal tax, the amount of which is determined by the tax base and the tariff (the amount due per tax base unit). The tax base determines the way in which the sewerage tax burden is allocated among the connected parties. The tax could be the same for each connection, or the tax base could result in differences in individual sewerage tax assessments (e.g. on the basis of drinking water consumption).

The new-style sewerage tax is a municipal tax the amount of which may not be set proportional to the income, profits, or property of the taxpayer.

The legal basis of the current sewerage tax (which may be levied for another two years after the Municipal Water Tasks Establishment and Funding Act came into effect on 1 January 2008) lies in section 229 of the Municipalities Act, the contents of which are reproduced here for added information (see the ‘Section 229’ text frame).

Rather than being a general tax, the sewerage tax based on section 229 of the Municipalities Act is a retribution, which means that there must be some sort of individual quid pro quo, i.e. the taxpayer must be connected to the municipal sewerage system. In addition there must be a clear relationship between the amount of sewerage tax paid and the benefit to the taxpayer.

Another important principle is that sewerage tax may not yield a profit, and the same applies to the new sewerage tax! This means that the estimated total return of the sewerage tax may never exceed the estimated total cost of sewerage management.

More information about the allocation of costs is included in the Urban Drainage Guideline, module D1300, ‘Allocation and recovery of costs’ *(Toerekening en dekking van kosten*). In 2007 an ‘Aid to cost allocation of dues and tariffs’ (*Handreiking Kostentoerekening leges en tarieven*) was published (developed by the Ministry of the Interior and Kingdom Relations), which describes how and which costs can be allocated to fees, dues, and tariffs that may not show a profit.

Tax base
Both the new and the old sewerage tax are to be paid by the connected population and businesses according to a certain tax base. Several possibilities for this exist, all of which are subject to strict regulations. They include a fixed fee per connection, a fee based on drinking water consumption (price per m^3), drinking water consumption with a certain allowance (up to 150 m^3, 150 – 500 m^3, 500 – 1000 m^3, etc.), an amount per length of sewer for the premises, an amount depending on the economical value of the connected premises (real estate value).

Municipalities Act

Section 229
1. Dues can be charged for:
   a. the use in accordance with the assigned use of municipal property intended for public services or of works or facilities intended for public services that are being managed and maintained by the municipality;
   b. the use of services provided by or on behalf of the municipal executive;
   c. the providing of entertainment that makes use of facilities established by or with the collaboration of the municipal executive, or for which a special provision is made in the form of supervision or otherwise by the municipal executive.
2. For the application of this section and the first and fourth section of this chapter, the dues referred to in the first subsection are considered municipal taxes.

Section 229a
The dues referred to in section 229, first subsection, sub a and b, can be charged by the municipality that allows the use of the property, works, or facilities, or provides the services, irrespective of whether the taxable fact occurs within or without the municipality’s domain.

Section 229b

1. In bye-laws on the basis of which dues are charged as referred to in section 229, first subsection, sub a and b, the tariffs will be set so that the estimated returns of the dues do not exceed the relevant estimated expenses.
2. The expenses referred to in the first subsection include:
   a. contributions to designated reserves and facilities for the necessary replacement of the assets involved;
   b. the sales tax which under the VAT compensation fund act gives entitlement to a contribution from said fund.

ASSIGNMENT
Find out how this works in your municipality. Is your house connected to the sewer system? If so, what is the tax basis and how much sewerage tax needs to be paid?

Cost allocation
On the basis of the Municipal Water Tasks Establishment and Funding Act a municipality can elect to raise one or two taxes (Municipalities Act section 228a, subsection 2). If a municipality decides to raise two separate taxes, the costs will also have to be allocated to each of the two taxes. A study was conducted in 2005 to determine a simple way of implementing this required allocation (source: 'Proposed allocation system for wastewater and rainwater disposal costs', *Voorstel toerekeningssystematiek kosten voor vuilwater- en regenwaterafvoer*, Grontmij, 31 October 2005; see also the water chain reports at www.minvrom.nl (Dutch text only).

With the introduction of two taxes, the costs are all immediately divided among wastewater and rainwater.

The report includes a proposal on how this should be done.

Table 4.4 Cost allocation

	Rainwater or groundwater	Wastewater	Mix (using formula)
Object/component			
Disconnection	X		
Storage/settling facility	X		
Drainage	X		
Pressurised sewerage		X	
Foul sewer system		X	
Combined sewer system			X
Individual treatment facility		X	
Infiltration facility	X		
Surface water system (rainwater storage)	X		
Rainwater treatment	X		
Storm drain system	X		
Improved separated sewer system			X
Replacement of combined sewer system with construction of rainwater sewer			X
Swale	X		

For those costs which initially cannot be directly allocated to wastewater or rainwater, or which according to the above table belong to the 'mix' category, an allocation formula is used.

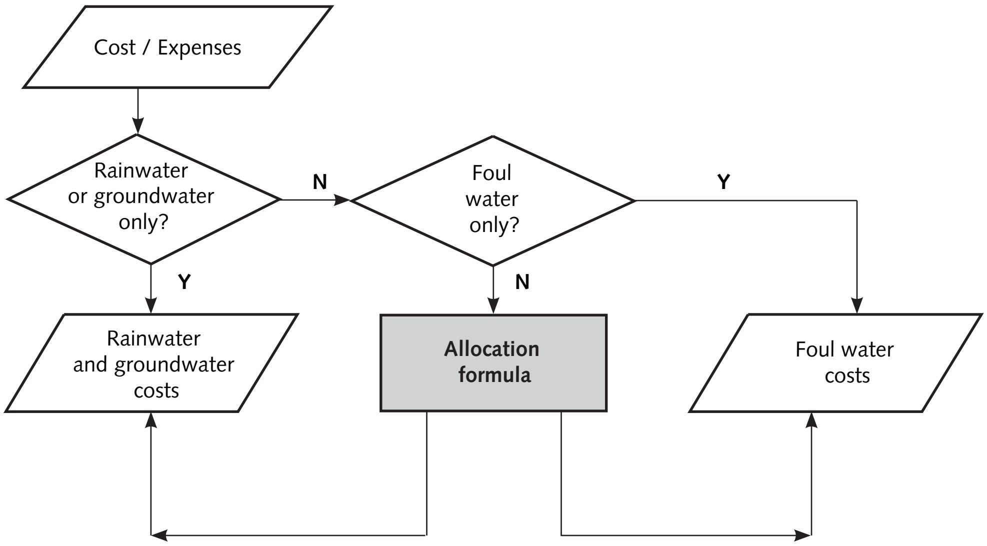


Figure 4.5 Cost allocation principle

For the sake of simplicity and transparency it was proposed to use a single allocation formula based on the replacement value of the sewerage. The figures entered in the formula are based on national index figures supplemented with local lengths for the sewerage and the number of pressurised sewerage units.

Table 4.5 Allocation formula calculation principle

Allocation formula 1a Replacement value: national index figure					
		Rainwater (part)	**Wastewater (part)**	**Rainwater**	**Wastewater**
		Price per m	**Price per m**		
Combined	500.0 km	€ 370	€ 280	€ 185,000,000	€ 140,000,000
Foul sewer	100.0 km		€ 410		€ 41,000,000
Storm Drain	100.0 km	€ 550		€ 55,000,000	
	No. of households		**Price per household**		
Pressurised sewerage	2500		€ 4,900		€ 12,250,000
Total				€ 240,000,000	€ 193,250,000
				55%	45%

4.4 Sewerage management and other municipal tasks

Sewerage forms part of the urban infrastructure. Therefore, sewerage management exists in a relationship with the responsibility for other types of urban infrastructure such as drainage, roads, urban planning, vegetation, public transport, urban water, and other pubic services, as shown in figure 4.6.

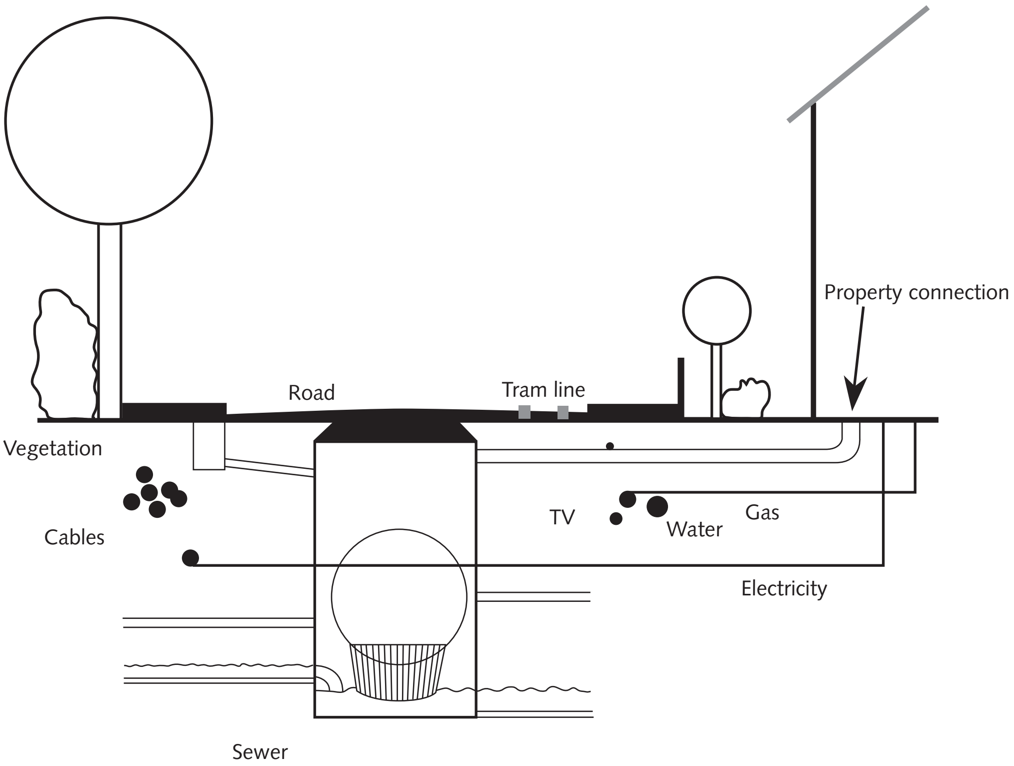


Figure 4.6 Relationships between sewerage and other types of urban infrastructure

It is important to know the relationships referred to above, because they can have a great impact on municipal sewerage policy. Once the various relationships are known, coordination of the (Municipal) sewerage policy with other fields of policy and with the policies of other authorities can take place.

As the scope of sewerage management increases, this aspect grows in importance. The relationships with the other departments become more intense.

- With the Building Inspection department, because the separation of wastewater and clean water calls for modifications to buildings. After all, unless water flows are presented separately, the municipality cannot collect them separately.
- With the Parks department, because the introduction of such facilities as swales requires special treatment of the topsoil, i.e. no playgrounds or cycle-cross fields, certain types of plants, etc.
- With the Public Furnishings department, because the treatment of surfaces can impact the handling of rainwater and the problems it may cause in extreme situations.
- With the Road Maintenance department, because the proper coordination of road works and sewerage work is an obvious way of cutting costs. It's not good practice to have to break up a recently resurfaced road to replace the sewer system below.

4.5 Sewerage Management in connection with the water chain

Several diagrams are in use in the Netherlands to indicate the place of sewerage management within the water chain. Two of these diagrams are reproduced below.
Figure 4.7 shows the relationships together with the responsible parties.

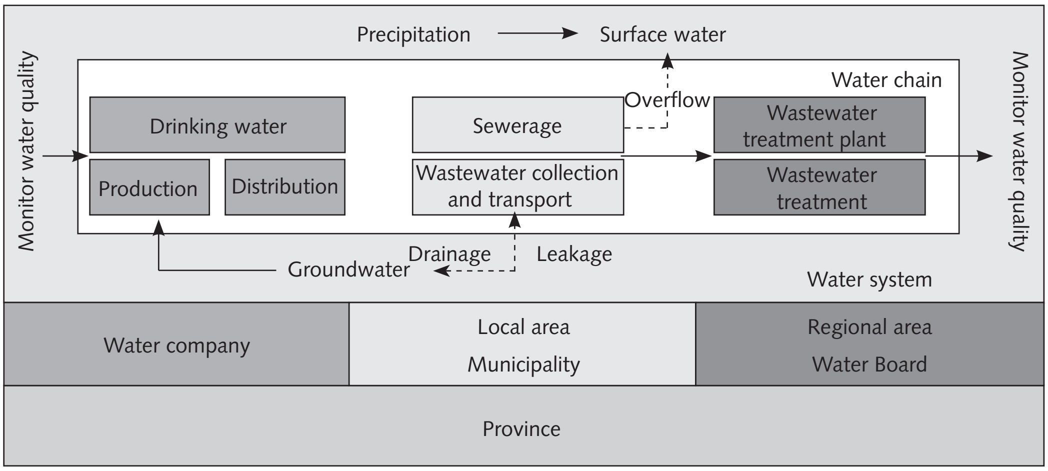


Figure 4.7 Water chain – water system relationship

The following diagram also distinguishes between the wastewater chain and the water chain. Sewerage and wastewater treatment plant together form the wastewater chain. With drinking water added, this becomes the water chain.

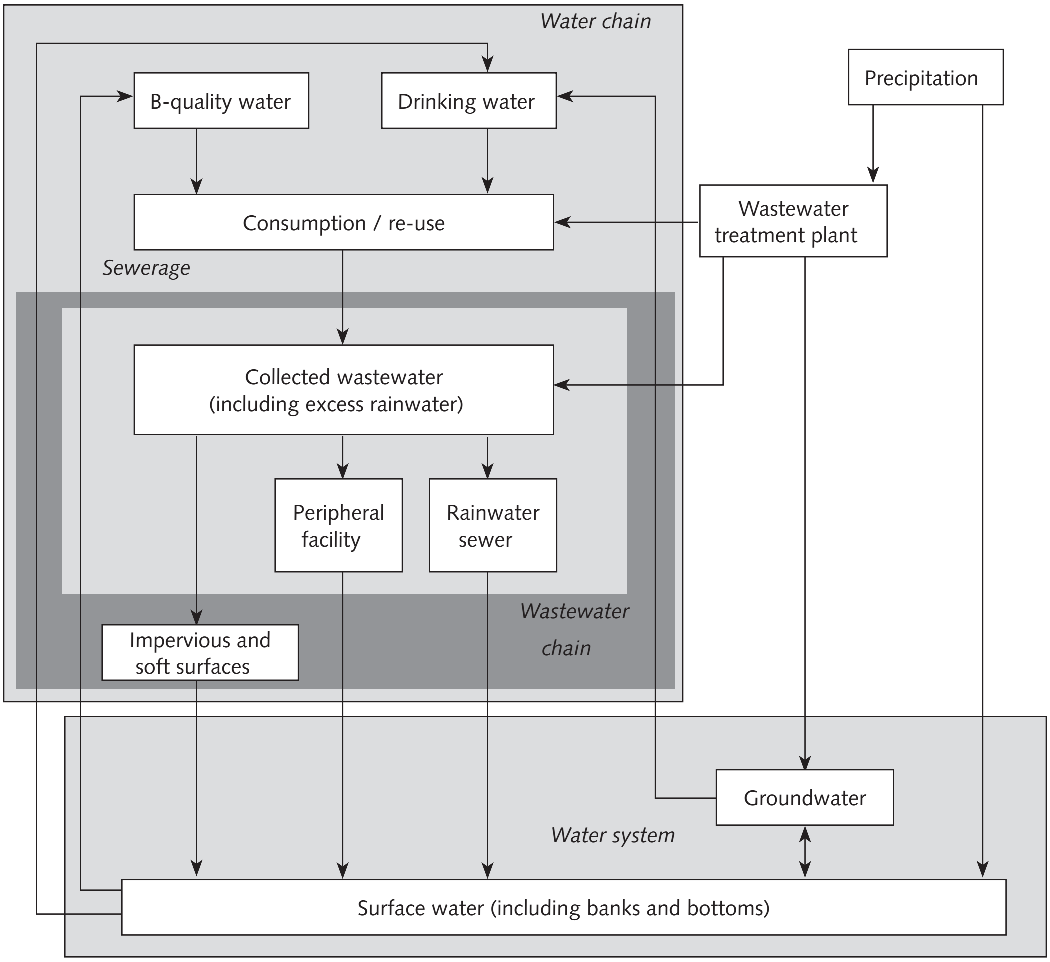


Figure 4.8 Water chain and water system (Urban Drainage Guideline module A1100 2003, RIONED Foundation)

Both diagrams show that there are numerous relationships between the various components of the water chain and of the water system. This means that any intervention in one component will also affect the other components. This is why collaboration is so important. We have already seen in chapter 3 that collaboration is one of the elements included in the Water Chain Administration Agreement and that it will be embedded in the Water act.

Self-assessment questions for chapter 4

1. Name the municipal water tasks and water-related responsibilities.
2. What does efficient sewerage management entail? Within the framework of municipal sewerage management, give a few examples of objectives with their functional requirements and performance criteria.
3. In your own words, describe the 'sewerage figure of eight' shown in figure 4.3, which needs to be followed in order to establish efficient municipal sewerage management.
4. What are the means required for achieving efficient sewerage management in a municipality, and why?
5. Within the framework of municipal sewerage management, name the partial tasks of which a major part must be performed by staff employed by the municipality? Explain why.
6. The purpose of the cost recovery plan in the Municipal Sewerage Plan is to ensure that all costs listed in the long-term cost list are offset by the returns. Name the main cost types and the main sources of income.
7. Under the new-style sewerage tax regime, the municipality can elect to raise two separate taxes, one to manage wastewater, and one to manage rainwater and groundwater. What do you know about the way the costs for these responsibilities are allocated to the two taxes?
8. Sewerage Management is not a responsibility that stands on its own. With whom, and about which other municipal policy domains and tasks should consultation and coordination take place within the municipal organisation?

5 Sewer calculations

This chapter focuses on the calculation of sewerage components in gravity sewer systems. Section 5.1 defines the fundamentals. Section 5.2 takes a systematic look at the design data that need to be known to carry out sewerage calculations. Section 5.3 discusses the considerations that determine the choice of system and the layout of the wastewater system. In section 5.4 you will find the required knowledge of hydraulics that will enable you to make a rough estimate of the flow in a sewer system. Section 5.5 finally, gives an impression of how practical sewer calculations are performed, and of the checks and criteria that apply.

5.1 Fundamentals

For a proper understanding of the salient features of a sewer system, you should look upon a sewer system as an underground space that is used to collect wastewater and excess rainwater. The sewer pipes carry the water, usually by gravity, to sewer pumping installations. The pumps in the sewer pumping installations take the wastewater from the sewer pumping installations and transport it to the wastewater treatment plant. The flow transported to the treatment plants consists of dry weather discharge (foul water) and wastewater, and in many cases includes rain-water, also known as storm drainage.

In the event that the sewer system becomes completely filled with the runoff collected from impervious surfaces, the water (mostly rainwater, possibly containing some wastewater), leaves the system through overflows. From this process description follow the main properties of sewer systems.

5.1.1 Properties of sewer systems

A gravity sewer system is characterised by:

- System type (combined, separated, or improved versions)
- Storage capacity
- Excess pumping capacity
- Runoff surface area

The storage capacity of sewerage systems is usually expressed in mm, and the excess pumping capacity in mm/h. The reason for this is that the precipitation load is normally expressed in mm of precipitation, with the precipitation intensity being expressed in mm/h. If the storage capacity in mm and the excess pumping capacity are known, the time to empty the system (the retention time) can be determined. This time should preferably be short (no more than say 20 hours) because:

- long retention times imply that the storage capacity will not be available fast enough if a second downpour occurs;
- long retention times may result in anaerobic sewage, which could result in odour problems and corrosion.

If the storage capacity and the excess pumping capacity are to be calculated, it is important to know the size of the runoff area. The runoff area is the total of impervious surfaces within a built-up area from which rain drains into the sewerage.

The excess pumping capacity is the part of the pumping capacity (pumping installation capacity) that is available for dealing with rainwater, expressed in m³/h or in mm/h relative to the impervious surface:

$$q_{epc} = \frac{Q_p - Q_{foul}}{10 * F_V} \tag{5.1}$$

in which:

q_{epc} = excess pumping capacity, in mm/h
Q_p = pumping capacity, in m³/h
Q_{foul} = foul water pumping capacity, in m³/h
F_V = runoff surface, in ha (hectares; 1 ha = 10,000 m²)

The storage capacity is the volume of the sewer system expressed in m³ or in mm relative to the impervious surface, in formula:

ASSIGNMENT
Check the units in the formula for calculating the storage capacity B in mm, and notice that the figure 10 in the denominator is necessary in order to make the formula's units match.

$$B = \frac{V_s}{10 * F_V} \tag{5.2}$$

in which:

B = lower sill storage capacity, in mm (storage capacity below the level of the sewer overflow)
V_s = system volume, in m³
F_V = runoff surface, in ha

Retention time is the time required to empty a sewer system that is filled to capacity.

$$T_l = \frac{B}{q_{epc}} \tag{5.3}$$

in which:

T_l = retention time, in hours
B = lower sill storage capacity, in mm
q_{epc} = excess pumping capacity, in mm/h

5.1.2 Schematics and modelling

To enable calculations to be performed on a sewer system, the real-world situation needs to be translated into a schematic equivalent. This process consists of two parts:

- Translating the sewer system into a schematic diagram or sewerage model.
- Describing the water flow using a calculation model.

Depending on the purpose, more or less simplification may be applied. In doing so, care should be taken to maintain a proper balance between both parts of the schematisation process. There is little point in combining a highly refined description of the water flow with a very simplified sewer system description.

In the simplest case, a so-called reservoir model is used. In a reservoir model the description of the sewer system has been reduced to a reservoir with an overflow (the sewer overflow) and a discharge opening (the pumping installation). The description of the water flow is minimised to assuming the conservation of mass, also referred to as the water balance:
In = Out + Storage Capacity

Sample calculation
In two hours, 21 mm of rain falls onto on an impervious surface. The sewer system has a storage capacity of 7 mm, and the excess pumping capacity is 0.75 mm/h. Calculate the overflow quantity.
Solution: the overflow quantity of the 21 mm of rain will be:
$21 - 7 - (2 \times 0.75) = 12.5$ mm

The usefulness of a such a model is limited, for it will not reveal anything regarding such matters as flood points or flow rates in pipes. What the simple model can do, at least in flat areas, is to indicate the frequency with which the overflow will be activated, and allow a reasonably close estimate to be made of the volumes of wastewater discharged from overflows.

The most detailed combination in current use is a 'complete' sewerage model in combination with a one-dimensional dynamic description of the water flow. A complete sewerage model contains all of the following elements:

- Manholes
- Sewers (schematically reduced to a prismatic tube element between two manholes)
- Overflows
- Pumping installations

Since the flow description varies over time, it is essential for the sewerage model to contain every element in order to correctly describe the variation over time of the system's storage capacity. This means that the basic data used for the model must be of a high standard, that is to say both accurate and complete.

An intermediate form used in use until a few years ago was based on a simplified model in combination with a stationary description of the water flow, which disregards any flow variations over time. In the sewerage model, the sewer system is simplified to include only the main discharge routes in combination with all the discharge elements (overflows and pumping installations). A stationary model can be used to say something about the drainage capacity of a sewer system. Depending on the level of detailing of the sewerage model, locations presenting an overload risk (resulting in water on the road) can be indicated. Figures 5.1, 5.2, and 5.3 show some examples of the different types of schematic simplification in use today and in the past.

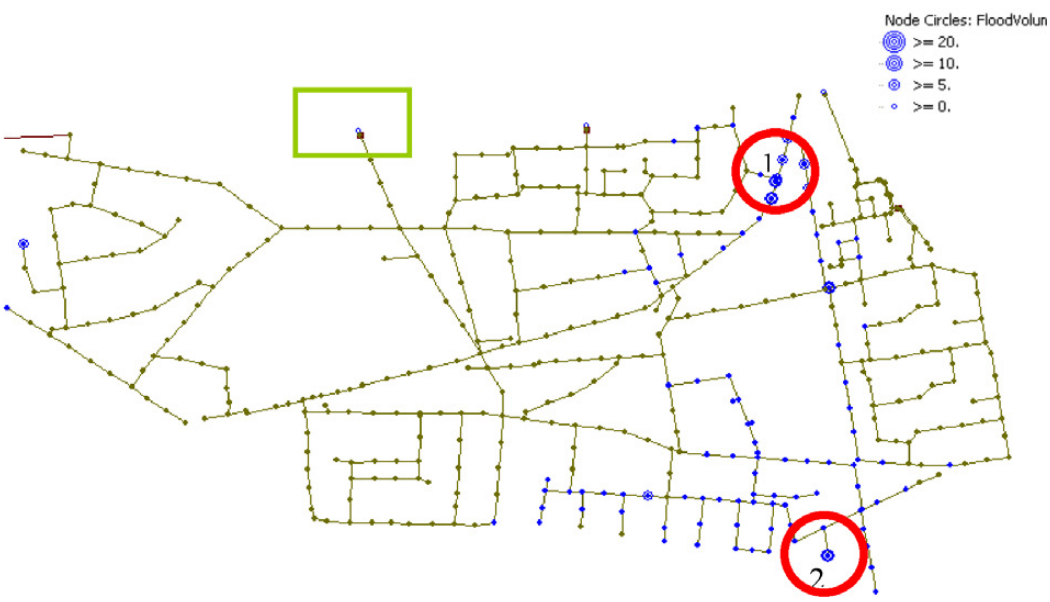


Figure 5.1 Example of a complete sewerage model. It includes every manhole and every sewer section. The blue circles indicate the places where overloads may occur and could result in flooded roads.

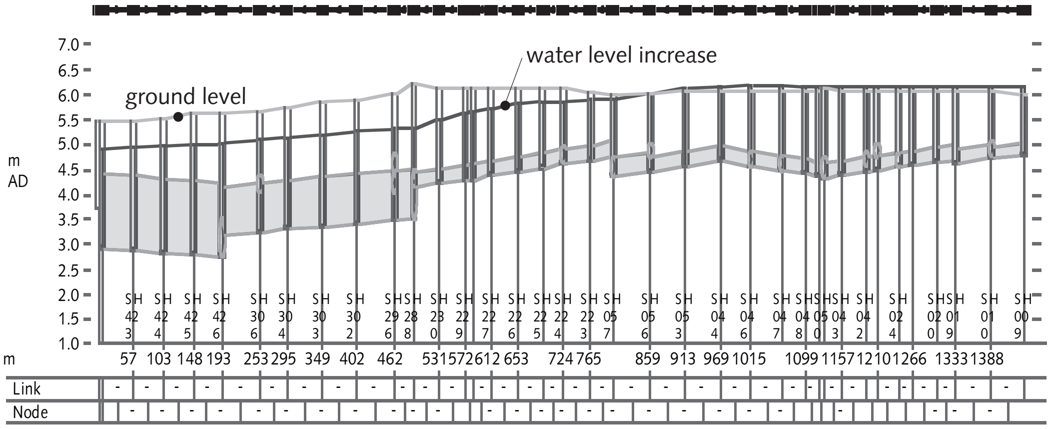


Figure 5.2 Example of a schematically simplified main discharge route in a stationary model. The blue line indicates the piezometric level, the green line is ground level. This figure shows that the sewerage on the right-hand side is being overloaded, resulting in flooded roads.

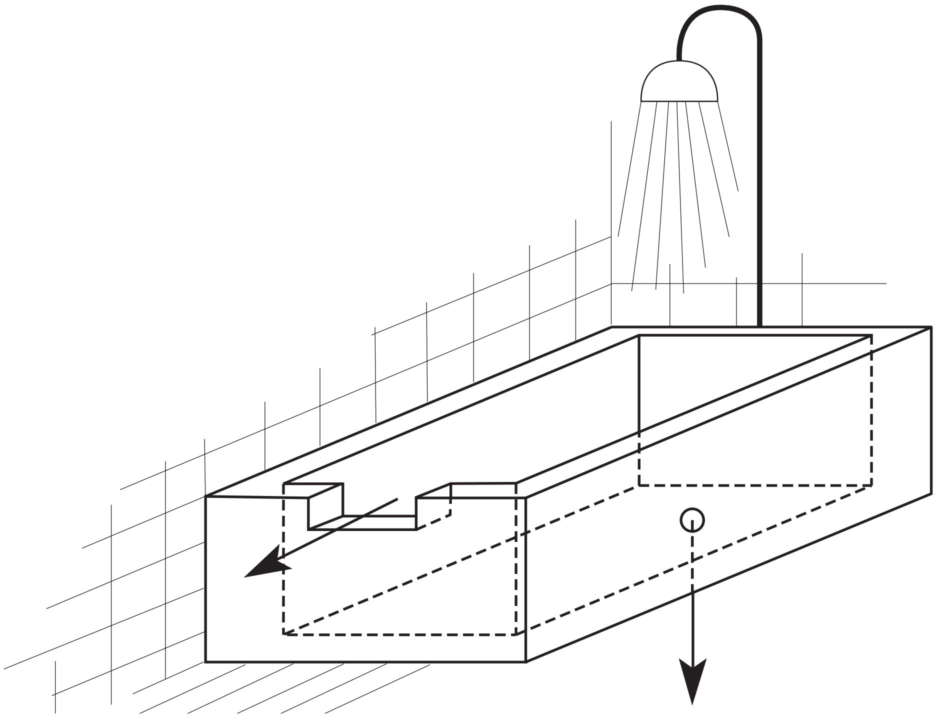


Figure 5.3 A sewer system modelled as a bathtub, i.e. using the reservoir model. The shower represents the real shower, the plug hole is the sewer pumping installation, the bath overflow is the sewer overflow, and the bathtub itself represents the storage capacity of the sewer system.

5.2 Design data

5.2.1 Preconditions

Preconditions are defined as conditions that must be considered as given, due to the nature of the location.

The preconditions in a hydraulic design for a sewer system are formed by:

- Street plan (urban design)
- Ground levels
- Presence, location, and level of surface water
- Zoning regulations
- Required protection against hydraulic overload (flooded roads)
- Admissible impact on the environment (in particular regarding discharges into surface water from sewer overflows)

In addition the following design properties apply:
- Minimum diameter
- Minimum depth
- Typical filling level
- Minimum shear stress
- Maximum flow rate

Minimum diameter
A minimum diameter for sewers is dictated by the following requirements:
- Minimum risk of blockage
- Ease of connection
- Ease of access for inspection and cleaning

For rainwater sewers and combined sewers, a minimum diameter of 300 mm is usually assumed, with 250 mm being assumed for foul water sewers.

Minimum cover
Sewers must be installed at a depth that minimises the risk of damage from frost and passing traffic. In the Netherlands the minimum cover depth is 0.8 m, see figure 5.4.

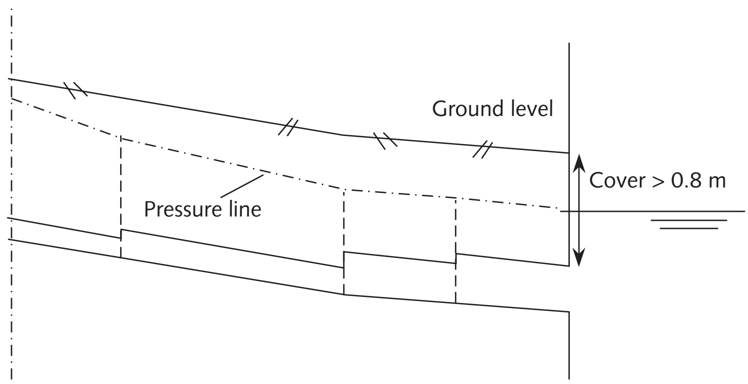


Figure 5.4 Minimum sewer cover

Typical filling level
The filling level is defined as h/D, in which h represents the water level in the sewer, and D the diameter. For the design of a foul water system in separated sewerage the filling level is 30 – 50%. Assuming a typical filling level of 50%, the actual capacity of the sewers at full level is double the design capacity. This wide margin is maintained to allow for exceptional conditions. These could include an unforeseen expansion of a residential area discharging into the system, and more specifically the need to accommodate rainwater that is discharged into the foul water system as the result of a faulty connection.

Another very important reason to set the typical filling level between 30% and 50% is to do with the fact that in conditions in which the wastewater lacks oxygen (becomes anaerobic), there is a risk of cement-based materials being affected. If the filling level becomes too high, the water surface is relatively small compared with the water volume, which reduces the gas exchange interface between the sewage and the sewer atmosphere, and increases the risk of the water becoming anaerobic.

ASSIGNMENT:
Argue why this is so, given an equilibrium flow and the following relationship for the shear stress:

$\tau = \rho g R_h i_b$ *in which* τ *represents the shear stress,* R_h *the hydraulic radius, g the gravitational field,* i_b *the sole gradient and* ρ *the density of water, and given the following rule of thumb for the sole gradient:*

$i_b = \frac{1}{D}$ *in which D represents the diameter of the pipe in mm (i.e. a 'round 400' pipe will be laid at a sole gradient of 1:400).*

Self-cleansing capability

For both combined systems and the rainwater system of a separated system, the required discharge rate of precipitation dictates the dimensions of the sewers and other components of the systems.

In addition to rainwater, a combined system has to be able to cope with domestic and industrial wastewater. The filling level of the sewers in dry weather conditions will be considerably lower than during precipitation of any importance. In dry weather conditions the flow rate in the sewer must be such that solid particles contained in the wastewater are carried off by the flow. This is known as the self cleansing velocity. In Anglo-Saxon countries a sewer is considered safe from settling if the flow rate is at least 0.60 m/s. Strictly speaking it would be better to use a certain minimum shear stress value (0.5 – 1.5 N/m²), because this would tie in better with the essence of the problem, which is sediment transport. However, it would be difficult to decide on the exact value to be used, since research has shown that the critical shear stress for sewer sludge can vary widely. Even so, for the Dutch situation a practical rule of thumb has been defined for the minimu gradient is defined as $i_{min} = 1/D$, in which D represents the pipe diameter in mm.

Maximum flow rate

The maximum permissible flow rate in sewers depends on:

- The susceptibility to erosion of the pipe material. A glazed stoneware pipe is practically immune to erosion, whereas a concrete pipe will not erode as long as the flow rate is less than 12 m/s for pure water, or 2 to 3 m/s for water containing sand or other solids.
- The duration of the scouring action. A wastewater sewer is practically in continuous use, reducing the permissible flow rate to 4 m/s, whereas a rainwater sewer is subjected to short peak loads only during which higher flow rates can be allowed.

The assessment of the design requirements will be discussed in more detail in sections 5.5.4 and 5.5.5.

5.2.2 Sewer system loads

The loads to which a sewer system is subjected consist of two components:

- Foul water load (domestic and industrial wastewater, infiltration, drainage)
- Rainwater load

The following sections will discuss the way in which these loads are calculated for design purposes.

Foul water load

The foul water load consists of domestic wastewater, industrial wastewater, infiltration, and drainage water.

The daily amount of domestic wastewater depends on the drinking water consumption per head of the population, the losses, and the number of persons. The design of a sewer system must allow for possible future developments such as population growth and changes in the pattern of drinking water consumption. Another factor to take into account is the variation of the amount of wastewater throughout the day.

Drinking water consumption per person

The drinking water consumption depends on the local standard of living and the climate conditions. A low standard of living can mean a lack of flushing lavatories. A high standard of living will mean that, in particular in subtropical and arid areas, as well as in the tropics, large quantities of drinking water will be used to water gardens and fill swimming pools, with lots of water also being used for bathing.

The average drinking water consumption in the Netherlands is approximately 128 litres per person per day. The drinking water consumption per person can be subdivided according to the various domestic activities such as laundry, cooking, washing, flushing lavatories, and dishwashing. Of all the drinking water supplied to end users, only about 40% is used for personal hygiene, drinking, and cooking. The remaining 60% of the drinking water is used for purposes that could just as well be served by water of lower quality. This has resulted in an increased interest in methods for converting water of lower quality than drinking water for such purposes. Unfortunately, the environmental advantages of such systems turn out to be limited. In addition there is the very real risk of crossed connections, with water from the household water system (i.e. of insufficient quality) being used as drinking water, resulting in disease. These problems have caused an experiment with a household water network to be abandoned in a newly constructed residential area in Utrecht (*Leidsche Rijn*).

Losses
Part of the drinking water supplied to end users is lost and will not drain into the sewerage. Losses include leakage from the distribution system, water used in gardens, or water evaporating from laundry. The total losses in the Netherlands amount to approximately 5% of the drinking water consumption, so the daily amount of wastewater comes down to approximately 120 litres per head of the population.

The difference between wastewater discharge and drinking water production is not the result solely of climatological conditions and the local standard of living. Losses through leakage from the distribution system can help explain a major part of the difference. In some countries these losses can amount to between 10 and 50% of the drinking water production. In the Netherlands losses through leakage are less than 5% of the water production. Table 5.1 lists the quantities of water supplied (or rather, the drinking water production) and the quantities of wastewater that are discharged for a number of different locations.

Table 5.1 Drinking water supply and wastewater quantities in litres per person per day

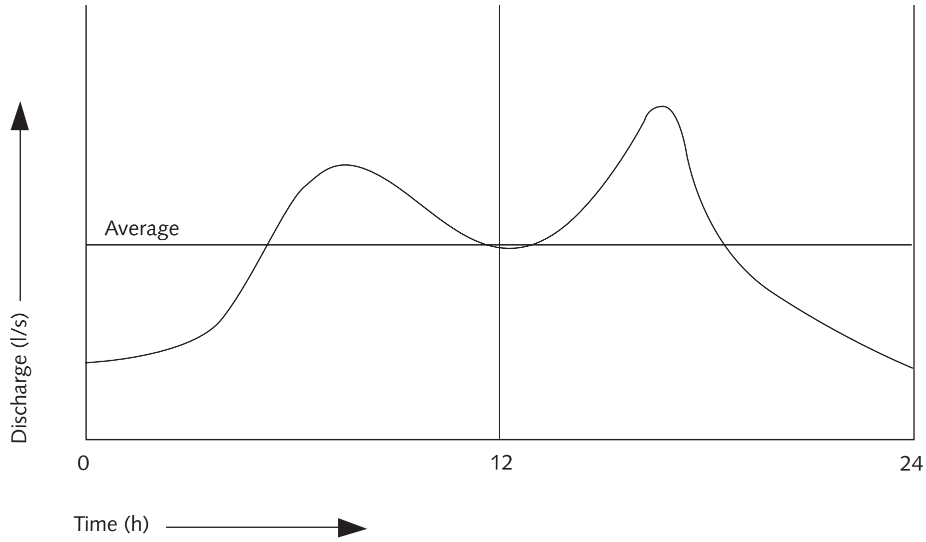
Location	**Drinking water**	**Wastewater**
Las Vegas (US)	1,560	760
Little Rock (US)	190	190
Wyoming (US)	570	300
Boston (US)	550	530
Cairo (Egypt)	800	150
Amsterdam (part of)	130	209
Grand Rapids (US)	670	720

In many locations the wastewater quantities are considerably less than the quantities of drinking water supplied. In Amsterdam and Grand Rapids however, the wastewater quantities exceed the water supply. In the case of Amsterdam this must be attributed to the infiltration of groundwater into the sewerage. Something similar is probably happening at Grand Rapids.

As the above shows, basing the dimensions of separated sewer systems on the drinking water production can result in either oversized or undersized foul water sewers.

Daily fluctuations
The demand for wastewater disposal does not remain the same throughout the day. The amount of wastewater produced during the night is small. Most of the wastewater needs to be discharged during a 10-hour period of the day. The demand for drinking water on the other hand shows marked peak values during mornings and evenings (see figure 5.5).

Figure 5.5 Daily fluctuations of foul water production



In the Netherlands it is customary in the design of sewer systems to allow for a domestic wastewater flow of 12 litres per person per hour. This assumes that the total quantity of domestic wastewater of 120 litres per person per day is discharged during a 10-hour period. Therefore, the peak factor normally applied in the Netherlands is as follows:

- Peak wastewater production: 120 / 10 = 12 litres per person per hour
- Average wastewater production: 120 / 4 = 5 litres per person per hour
- The peak factor therefore is: 12 / 5 = 2.4

As it turns out, the value of the peak factor varies between different countries, for reasons that aren't always very clear. Of much greater importance for the proper operation of the wastewater system is the risk of rainwater drains being connected to the foul water sewerage, which may overload the system. The following paragraphs may provide an explanation.

Explanation

The peak discharge per inhabitant in the Netherlands amounts to 12 l/h. Assuming a runoff surface area of 60 m² per person this amounts to a foul water discharge of 0.2 mm/h. Foul water sewers are designed for a typical filling level of 50%. The filling level equals the water level in the sewer divided by the sewer diameter. The actual capacity of the sewers at full filling level, based on a typical filling level of 50%, is about double the design capacity. This ample margin is maintained to allow for the possible future expansion of the area discharging into the system, and in particular the need to accommodate rainwater discharged into the foul water system as a result of incorrect connections. Several times per year the rainfall amounts to 20 mm/h. This means that only 0.2/20 (i.e. 1/100th) of the impervious surface needs to discharge into the foul water system for the full capacity of the latter to be reached. If any more of the rainfall is discharged into the foul water sewerage, there is even the risk of wastewater entering premises through floor gullies, or of roads being flooded as manhole covers are lifted by the water pressure.

Industrial wastewater

The quantity of industrial wastewater (trade effluent) varies considerable between types of industry. When a sewer system is being designed for a newly developed district, it is often not yet known which businesses will settle in the area. In such cases the design is based on a load of 2 litres per second per hectare. This load is derived from the gross surface area, since the impervious runoff surface area is unknown at the time the design is being completed.

If the sewer system is to cover an existing built-up area, the wastewater quantity can be calculated using information from the local drinking water company. Please note that some industries supply their own water by pumping up groundwater. In such cases the relevant authorities will have issued an extraction permit (for industrial extractions above 150,000 m^3 per year this would be the provincial executive, otherwise it is the water board). The water consumption of the industry in question can be derived from the permit, and the sewerage can then be dimensioned accordingly. You should bear in mind however that certain industries (e.g. the soft drinks industry, breweries) recycle part of the water they use, or have their own water treatment plant and therefore do not discharge into the sewer system.

Infiltration

Sewer systems should be watertight. However, older systems often aren't, in particular in areas with a poor soil structure. If the water table is high, groundwater will penetrate the sewer in the form of infiltration, to be carried off as wastewater. Designs for sewer systems should allow for an infiltration rate of 0.2 m^3/h per kilometre of sewer.

The following should be noted. The average uncovered surface per dwelling of an area served by sewerage is 140 m^2. This includes a length of sewer of approximately 7 m^1 per dwelling. If we take this into account, an infiltration rate of 0.2 $m^3/(km \times h)$ means that approximately 87.6 mm of the annual precipitation falling on uncovered surfaces is carried off through sewer infiltration. Recent research has shown that sewerage laid in soil with poor load-bearing properties, infiltration may be of the order of magnitude of 1 $m^3/(km \times h)$. This means that in these cases approximately 440 mm of the precipitation falling onto uncovered surfaces is carried off through the sewer system. This figure of 440 mm more or less matches that of the average effective precipitation, i.e. the precipitation that is added to the groundwater every year. The effective precipitation equals the total annual precipitation minus the total annual evaporation. This implies that water tables will rise if leaking sewers are sealed. Therefore, the sealing of leaking sewers must be undertaken with care, or cellars and basements could flood, and houses could become intolerably damp.

ASSIGNMENT

Can you confirm that an infiltration rate of 0.2 m^3 per kilometre of sewer equals a precipitation of 87.6 mm onto the average uncovered surface area of 140 m^2 per dwelling? The important thing is to know that each house has an average sewer length of 7 m^1.

Drainage water

Drainage water is groundwater that is extracted from the soil through land drains in order to control the groundwater table.

Water management authorities in general object to the transport of the relatively clean drainage water to a wastewater treatment plant. In certain cases in which it impossible to discharge the drainage water into open water, permission is given to dispose of the drainage water by discharging it into the sewer system.

When designing a system and when performing calculation checks to assess the operational qualities of the system, the transport of drainage water is not taken into account, unless the quantities are known. If they are unknown, it is assumed that any volume of drainage water is included in the volume of infiltration water that leaks into the sewer system.

Precipitation

In the Netherlands a major part of the precipitation is carried off by the sewer system.

Part of the precipitation does not appear as runoff and therefore does not contribute to the sewerage load. It is essential that the quantity of precipitation that actually appears as runoff be estimated with some accuracy, since an incorrect figure could easily result in an oversized or undersized sewer system.

The runoff behaviour depends on the extent to which the following phenomena occur:

- Interception
- Evapotranspiration
- Infiltration
- Retention in puddles

Interception (moistening losses) is what happens to the part of the precipitation that is adsorbed by the surface in such a manner that it does not contribute to the runoff.

Evapotranspiration is what happens to rainwater that evaporates directly at ground level, on vegetation, and on buildings, and to the water that evaporates indirectly through vegetation. Infiltration is what happens to water that penetrates the (covered or uncovered) surface and sinks into the soil.

Retention in puddles occurs when the initial runoff stays behind in depressions in the surface. In sewerage design the runoff behaviour is usually included in the calculations in the form of a runoff coefficient. The runoff coefficient represents the part of the total precipitation that actually results in runoff. Table 5.3 provides some typical values.

Table 5.3 Runoff coefficient

Type of surface	**Runoff coefficient**
Slate roof	0.95
Tiled roof	0.90
Flat roof	0.50 – 0.70
Tarmac	0.85 – 0.90
Concrete pavers	0.75 – 0.85
Cobbles	0.25 – 0.60
Gravel	0.15 – 0.30
Bare surfaces	0.10 – 0.20
Parks, vegetation	0.05 – 0.10

In designs for the Netherlands the runoff coefficient for impervious surfaces (roofs and roads) is usually set at C = 1, and for absorbent surfaces (parks, gardens) at C = 0. When dimensioning sewer systems in the Netherlands, only the impervious surface is included in this rough estimate. Although in certain situations the uncovered terrain can also contribute to the load placed on sewer systems, this tends to be ignored in our country. This can be explained as follows.

In most built-up areas 50% of the surface area consists of impervious surfaces, of which 60% is taken up by roads, squares, and pavements, and 40% by roofs. Of the roads, 75% have a tarmac top, and 25% are cobbled. The roofs consist of flat and sloping roofs, in roughly equal parts, i.e. 50% each. The absorbent surfaces consist of gardens and other vegetation. In the event of heavy rain, on average about half of this uncovered surface can drain into the sewer system, partly by way of pavements and roads. If we assume a total built-up surface of 100%, a picture emerges as shown in table 5.4.

	Proportion	Runoff coefficient	Relative proportion
Tarmac roads	22.5%	0.90	0.20
Cobbled roads	7.5%	0.50	0.08
Sloping roofs	10.0%	0.90	0.09
Flat roofs	10.0%	0.70	0.07
Runoff uncovered	25.0%	0.15	0.04
Non-runoff uncovered	25.0%	0.00	0.00
Total	**100%**		**0.48**

Table 5.4 Calculating the composite runoff coefficient

The runoff coefficient indicates which part of the precipitation of the relevant surface results in runoff reaching the sewer system. The table shows that the runoff coefficient for the total built-up surface area is 48%, which is only 2% less than the percentage of impervious surface present within the built-up area. This is the case in practically every built-up area, which is why an assessment of the operational qualities of sewer systems is based exclusively on the runoff coefficient of the impervious surface. The runoff coefficient to be used in such cases is of course equal to 1.

Based on many years of experience Dutch sewer systems are designed to be able to cope with a continuous precipitation intensity of 60 litres per second per hectare. For increased safety a value of 90 litres per second per hectare is sometimes assumed in areas laid out on an incline. The hectares figure to be used includes the total impervious surface area.
The design rain intensities referred to show that the real-world conditions are extensively simplified.

ASSIGNMENT
Convert the continuous rain intensity of 60 litres per second per hectare into a continuous rain intensity measured in mm/h.

Rain duration lines
As we know, rain in the Netherlands does not fall at a continuously even rate. A heavy late-summer thunderstorm generally displays a very high rain intensity during a short period that lasts from half an hour to a few hours. During winters, when endless successions of depressions traverse our country, the rain can keep on coming for days on end, even though the rain intensity will not be as high as in a thunderstorm. Rain duration lines give some indication of the variability of the precipitation intensity. These rain duration lines are compiled on the basis of historical rain observation values. Rain duration lines show the total precipitation to be expected during a certain period (e.g. half an hour, one hour, 4 hours, 8 hours, etc.) with a certain probability.

Rain duration lines are very useful when designing and analysing sewer systems, stretches of open water, storage basins, and storage/settling basins. They indicate the likelihood that a certain amount of precipitation will fall during a certain time. The precipitation quantities for rain durations of 4 hours, 8 hours, 1 day, up to and including 9 days, for different recurrence periods, have already been listed in chapter 3. Figure 5.5 shows the rain duration line from the Heidemij/LD publication. For a number of recurrence periods, indicated by with T = X years, the vertical axis shows the total precipitation expected for a certain duration of the rain (horizontal axis).

Figure 5.6 Rain duration lines

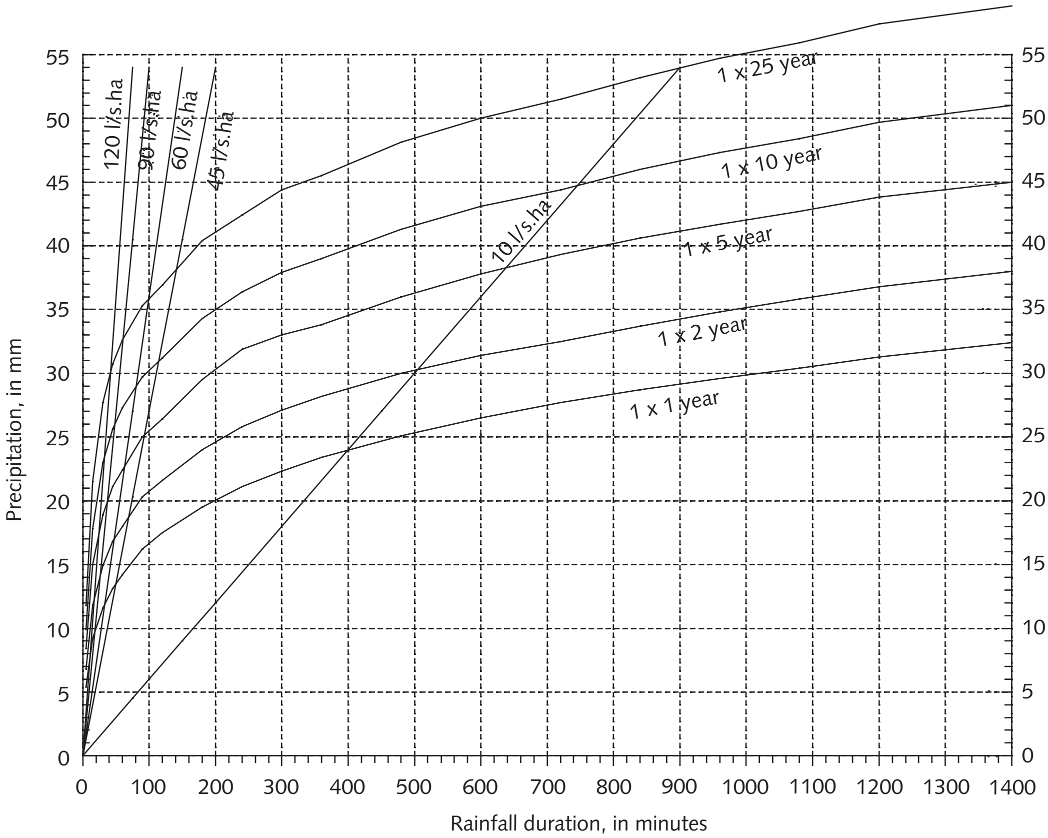


Figure 5.6 shows that on average once every five years (T = 5) a rainfall duration of one hour should be expected to produce 21.6 mm of rain. The figures also show that the rain intensity decreases with a longer rainfall duration. For the same recurrence period (once every five years) for example, a 4-hour duration will produce 31 mm of rain. It is important to note that the rain duration lines do not provide a realistic description of the precipitation during the rainy periods that occurred. The rain duration lines indicate the total precipitation during a certain period, but the period may have included dry spells.

5.3 System choice and layout

5.3.1 System type

The physical layout of an urban district directly affects the choice of sewer system and the cost of installing it. This is the case particularly in the low-lying parts of the Netherlands. Also, the presence of, as opposed to the need to lay out, large stretches of open water is of great importance.

For the discharge of rainwater and wastewater, the available options are a combined system and a separated system. The costs of installing a separated system are determined to a large extent by the availability of open water into which the rainwater system can discharge its contents. In the low-lying parts of the Netherlands open water like this often is already available in some way or needs to be constructed in order to maintain the desired groundwater table. In the higher parts of the country there is usually no need for open water to help in maintaining the water table. In such cases a separated sewer will be more expensive to build and maintain than a combined system, since the rainwater will have to be transported through sewers with dimensions that need to increase as the flow progresses downstream. The obvious choice then is to go for a combined system, although it should be noted that in the higher parts of the Netherlands another option that could be considered is to allow the rainwater to infiltrate into the ground from within the rainwater sewers, provided the permeability of the subsoil and the local groundwater situation make this possible.

For combined systems the presence and availability of open water also has a favourable effect on the construction costs. Such a system becomes less expensive to construct as the number of overflow locations increases where the system can discharge its contents during times of heavy rainfall. An aspect that should not be overlooked is that the discharge of water from the sewer system during overflow conditions can have an adverse effect on the quality of open water within built-up areas. This aspect must be taken into consideration during the urban planning stages.

With regard to the choice for an improved separated system no other considerations apply other than discussed above with regard to the separated system. The situation is different for an improved combined system though. The storage and settling basin, or some similar provision, that forms part of such a system, must be installed in a location where it can fill during times of rainfall that could lead to overflow. Generally speaking such a provision will be installed at the lowest point of the system, but it can also be located upstream of that point. Whatever the case, in view of the space requirements of such a provision, the location will have to be taken into account during the urban planning stages. Again, timely consultation between urban planners and sewerage experts is essential.

In uneven terrain it may be economically favourable to construct a partially combined and partially separated system. If a combined system is installed in hilly terrain, there is the risk of causing flood problems in lower regions in the event of heavy rainfall. One solution could be to install a separated system in the higher parts of the area, so only the wastewater needs to be discharged into the combined system of the low-lying area, thus avoiding the risk of flooding. Another solution is to increase the size of the main sewer of the combined system in the low-lying area.

The existing infrastructure can also affect the choice of system, in particular in cases of urban expansion. If the sewer system of a newly developed area is to discharge into an existing combined system, it may be necessary to install a separated system and allow only the foul water sewer to discharge into the existing combined system in order to prevent it from becoming overloaded.

If a newly developed area is to discharge into an existing separated system, in many cases the limited hydraulic capacity of the wastewater system will make it impossible to transport the additional flow of wastewater to the treatment plant through the existing system. In such cases the construction of a pressure pipe system or a separate transport pipeline could be the solution needed to transport the wastewater from the sewer pumping installation to the water treatment plant.

5.3.2 Network structure, depth

The structure of the network is of great importance when making hydraulic calculations of sewer systems. The structure of a network can be either dendritic (treelike, with the numbers of branches increasing upstream) or looped (rather like a grid). In a dendritic structure the flow of the water is known in advance, whereas in a looped layout there are various paths the water can follow on its way down.

There are specific benefits and drawbacks to each type of structure. In a dendritic system the failure of a single pipe (collapse, overloading) can result in the entire area upstream of the affected pipe being disrupted. In a looped system the water can follow an alternative route. In that sense a looped system is more robust than a dendritic system. On the other hand, in a looped system several pipes could suffer from insufficient flow rates, as a result of which, certainly in dry weather conditions, wastewater contents may start to putrefy, causing odour problems and corrosion of the pipe material. Practically all systems in the Netherlands are of the looped type.

As far as the installation depth of sewer systems is concerned, the following applies. A minimum ground cover of 0.8 m above the crown of the pipe is required. This is based on the need to spread the overhead load imposed by the soil and traffic as well as on the need to keep the sewers free from frost. Strictly speaking the gradient of the pipes should follow from a calculation of the necessary shear stress and/or filling level in foul water sewers. As a rule of thumb, for a first layout design a gradient equal to 1 divided by the pipe diameter in mm may be assumed. Therefore a circular pipe with a diameter of 400 mm will be laid at a gradient of 1:400. The background for this rule is that in this way a given filling level will result in a practically constant value for the bottom shear stress, regardless of the diameter of the pipe.

5.3.3 Location of special facilities
When designing a new system, it is essential that the locations of pumping installations, overflows, and discharge points be selected with care.
The following considerations apply to overflows:

- The availability nearby of surface water. If no other option is available, it is possible to add an overflow pipe behind an overflow, but this is an expensive solution that does not add to the storage capacity of the sewer system. Such solutions do occur in existing systems, as the result of changes in the layout of a district or other changes in circumstances.
- The vulnerability of the water into which the sewer system will discharge (choice of location in close consultation with the water quality management authority).
- The risk of nuisance (odour, visual pollution).
- The risk of public health problems (recreation, cattle drinking).

Most sewer pumping installations are of relatively small size and can be constructed entirely underground. In such cases, when selecting the location it is important to consider:

- Accessibility for maintenance without risk of personal injury or of causing traffic problems.
- Distance from buildings (to avoid problems with odours and possibly noise, although the latter seldom causes problems in the case of underground pumping installations).

Large pumping installations, usually the final pumping installations from which large quantities of wastewater are pumped to a water treatment plant, are often accommodated in buildings above ground. In this case the following considerations apply:

- Restricted choice of locations due to functions allocated in the zoning scheme.
- Requirements dictated by the building code.
- Risk of odour problems.
- Risk of noise problems.
- Accessibility.

Although the available sewer technology allows each of the locations to be selected more or less at will, it is advisable (provided all the other requirements make it possible) to follow the slope of the ground level, i.e. with the pumping installation at the lowest point, and overflows at the highest points. This will enable some savings to be made on earth-moving costs.

5.4 Hydraulics

5.4.1 Wastewater flow

Stationary flow in completely filled pipes
The flow of wastewater through a sewer system is a fairly complicated process. The flow is described by a system of partial differential equations that define a three-dimensional dynamic flow field. These equations are known as Navier-Stokes equations. This reader uses some of major simplifications:
- We consider the flow to be one-dimensional (i.e. we use only one velocity component, along the longitudinal axis of the pipe).
- We assume a stationary situation (constant in time).

This means that the calculation of the flow in a sewer system can be reduced to solving the following two equations:
- A stationary mass balance (cf. 5.4), also referred to as a continuity equation in the context of fluid mechanics.
- A simplified motion equation (cf. 5.5).

The stationary mass balance is defined as:

$$\sum_{i=1}^{i=n} Q_i + Q_B - Q_p = 0 \tag{5.4}$$

in which:
Q_i = inflow from pipeline i
Q_B = flow discharged into the node (hydraulic load)
Q_p = outflow from the node (pump flow)

In motion equations it is important to know whether pipes are completely filled, or only partially filled with a free water surface. We will start by looking at the motion equation for a completely filled pipe.

Completely filled pipes
The motion equation in a stationary situation with completely filled pipes indicates that the loss of energy ΔH (specified in m) that occurs along a flow length L (specified in m) is given by:

$$\Delta H = L \frac{Q|Q|}{C^2 R_h A_s^2} \tag{5.5}$$

in which:
Q = flow rate through the pipe, in m^3/s
L = length of the pipe, in m
C = Chézy coefficient, in $m^{1/2}/s$
R_h = hydraulic radius, in m
A_s = flow surface, in m^2

The value of the Chézy coefficient can easily be calculated using the following formula:

$$C = 18\log\left[\frac{12R_h}{k_n}\right] \tag{5.6}$$

in which:

C = Chézy coefficient

R_h = hydraulic radius

k_n = equivalent wall roughness according to Nikuradse

The hydraulic radius is defined as the quotient obtained by dividing the flow surface value by the wet circumference value. For a completely filled circular section pipe, this results in:

$$R_h = \frac{\frac{1}{4}\pi D^2}{\pi D} = \frac{1}{4}D \tag{5.7}$$

Sample calculation

A pipeline has a diameter of 1 m and a length of 100 m, the flow rate through the pipeline is 1 m³/s, the roughness of the wall is 2 mm. What is the loss of energy (in metres of water gauge/column) along the pipeline, assuming that the pipeline is completely filled?

The hydraulic radius is 0.25 m (equal to 0.25 * D)

The value of the Chézy coefficient is

$$C = 18\log\left[\frac{12R_h}{k_n}\right] = 18\log\left[\frac{12 * 0.25}{0.002}\right] = 18\log 1500 = 57.17 m^{\frac{1}{2}}/s$$

The wet surface area is $A_h = \frac{1}{4}\pi D^2 = \frac{1}{4}\pi 1^2 = 0.785 m^2$

The pressure difference in metres of water gauge (column) can now be calculated:

$$\Delta H = L\frac{Q|Q|}{C^2 R_h A_s^2} = 100 * \frac{1|1|}{57.17^2 * 0.25 * 0.785^2} = 0.198 m$$

The energy gradient is defined as $i_e = \frac{\Delta H}{L} = \frac{0.198}{100} = 0.00198$ i.e. approximately 1 in 500.

As a first indication of the roughness of sewer pipe walls the following can be used:

Table 5.5 Pipe wall roughness values for some materials

Material	**Wall roughness k_n (mm)**
Concrete	3.0
PVC	0.4
Glazed stoneware	0.5
Cast iron	2.0
Brickwork	5.0
PE	0.4
HPDE	0.4
Steel	1.5

Partially filled pipes
A stationary uniform flow in a partially filled pipeline is characterised by the fact that the gradient of the water level is equal to the pipe gradient, and to the energy gradient. This means that the gravity component in the direction of the flow is equal to the friction force acting on the water flow.
One of the times when this situation occurs is during dry weather conditions. It is important to be able to perform calculations for such conditions because the dry weather water depth must be known in order to determine whether any floating objects can carried off by the flow. It is equally important to be able to calculated the shear stresses that occur in order to establish self cleansing properties in sewers.

The motion equation now becomes:

$$i_b = i_e = \frac{\Delta H}{L} = \frac{Q|Q|}{C(h)^2 R_h(h) A(h)_s^2} \tag{5.8}$$

The problem lies in the fact that the flow surface, the Chézy coefficient, and the hydraulic radius now depend on the water level:

$$A_s(h) = \frac{1}{4} D^2 \arccos(1 - \frac{2h}{D}) - (\frac{D}{2} - h)\sqrt{hD - h^2} \tag{5.9}$$

$$R_h(h) = \frac{\frac{1}{4} D^2 \arccos(1 - \frac{2h}{D})}{2\sqrt{hD - h^2}} - (\frac{D}{2} - h) \quad (5.10) \tag{5.10}$$

A solution can be found by assuming an initial value and using a process of iteration, but an alternative is to use filling level diagrams. The calculation of the values of R_h, A_h and C has now become rather complicated, but for h = ½ × D (50% filling level) the values of R_h, A_h and C are easy to determine. Filling level diagrams (see figure 5.7 for an example) show the correlation between the equilibrium flows in a completely filled pipeline and in a partially filled pipeline.

Sample calculation
A sewer with a diameter of 400 mm needs to accommodate a flow rate of 0.050 m³/s. The design requirement is for a maximum filling level of 0.6. The roughness of the pipe wall is 1 mm. Calculate the required sole gradient.

The flow surface in the filled situation is

$$A_v = \frac{\pi}{4} D^2 = \frac{\pi}{4} 0.4^2 = 0.125 m^2$$

The hydraulic radius in the filled situation is R_{hv} = 0.25 D = 0.100m
The diagram (figure 5.7) shows that

h / D = 0.60 –> Q_{part} / Q_v = 0.66 –> Q_v = 0.050 / 0.66 = 0.076m³/s

Therefore is the value of the Chézy coefficient is

$$C_v = 18 log\left[\frac{12 R_{hv}}{k_n}\right] = 18 log\left[\frac{12 * 0.100}{0.001}\right] = 55.42 m^{\frac{1}{2}}/s$$

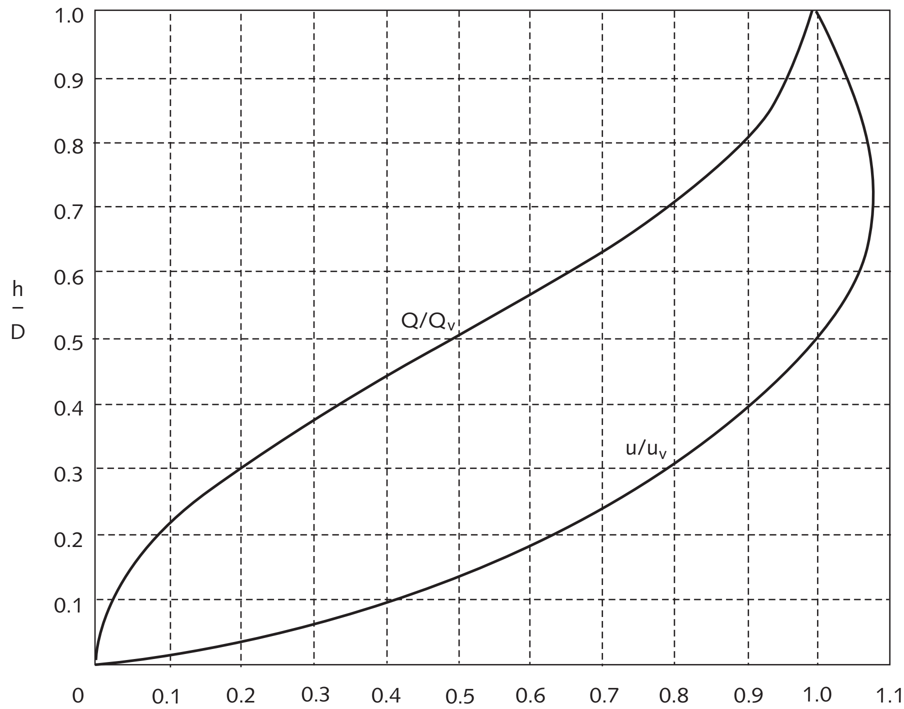
This results in a sole gradient of

$$i_b = \frac{Q_v|Q_v|}{C_v^2 R_{hv} A_v^2} = \frac{0.076^2}{55.42^2 * 0.100 * 0.125^2} = 0.001199 \quad \text{i.e. 1 in 834.}$$

The shear stress follows from $\tau = \rho g R_h i_e = \rho g R_h i_b$ in which the value for the hydraulic radius is given by formula 5.10, i.e. R_h = 0.1409 m

$\tau = \rho g R_h i_e = 1000 * 9.8134 * 0.1409 * 0.001199 = 1.55\ N/m^2$

Figure 5.7 Filling level diagram



Local head losses
In addition to friction losses resulting from the roughness of the pipe wall, energy is also lost as a result of so-called local head losses. These losses occur at bends, outlet structures, inlet structures, etc. Without going into too much detail, we will note that using local head losses in calculations is the consequence of assuming that the flow field is one-dimensional is. In places where the added complexity of the flow field is obvious, for example at pipe bends, the two velocity components we disregarded produce extra friction losses. Generally speaking the local head loss can be calculated as follows:

$$\Delta H_{locaal} = \xi \frac{u^2}{2g} \tag{5.11}$$

in which:
u = flow rate inside the pipeline, in m/s
g = gravitational field, in m/s²
ξ = head loss coefficient
ΔH_{local} = local head loss of energy, in m

The value for ξ depends to a large extent on the geometry of the structure. Some of the local head losses that often occur in sewerage will be discussed in the next paragraphs.

Manhole head losses

A manhole adds both inflow and outflow head losses. The following maximum values are used, although these depend on the design of the manhole:

- Inflow loss coefficient: 0.5 to 0.6
- Outflow loss coefficient: 1.0

This would make the total head loss across a manhole as much as 1.5 – 1.6 times the velocity of the main flow.

A sewer with a length of 100 m and a diameter of 400 mm is required to accommodate a flow rate of 0.050 m³/s. The pipeline is completely filled, the wall roughness is 1 mm, and there are two manholes in the pipeline. What is the loss of energy that occurs?

The flow surface in the filled situation is

$$A_v = \frac{\pi}{4} D^2 = \frac{\pi}{4} 0.4^2 = 0.125 m^2$$

The hydraulic radius in the filled situation is R_{hv} = 0.25D = 0.100m

Therefore the value of the Chézy coefficient is

$$C_v = 18 \log\left[\frac{12 R_{hv}}{k_n}\right] = 18 \log\left[\frac{12 * 0.100}{0.001}\right] = 55.42 m^{\frac{1}{2}}/s$$

Therefore the sole gradient is $\quad i_E = \frac{u^2}{C_v^2 R_h} = \frac{(0.397)^2}{(55.42)^2 * 0.1} = 0.000519$

resulting in a friction loss of

$\Delta H = i_E * L$ = 0,000519*100 = 0,0519m

The local head losses due to the manholes are

$\Delta H_{put} = \xi \frac{u^2}{2g} = 1.5 \frac{0.05^2}{2 * 9.813 * 0.125^2} = 0.012 m$ per manhole, i.e. a total of 0.024 m,

which is almost 50% of the friction losses caused by the pipe wall surface.

The head loss coefficient has been investigated in detail for a number of geometries (from Clemens 2001):

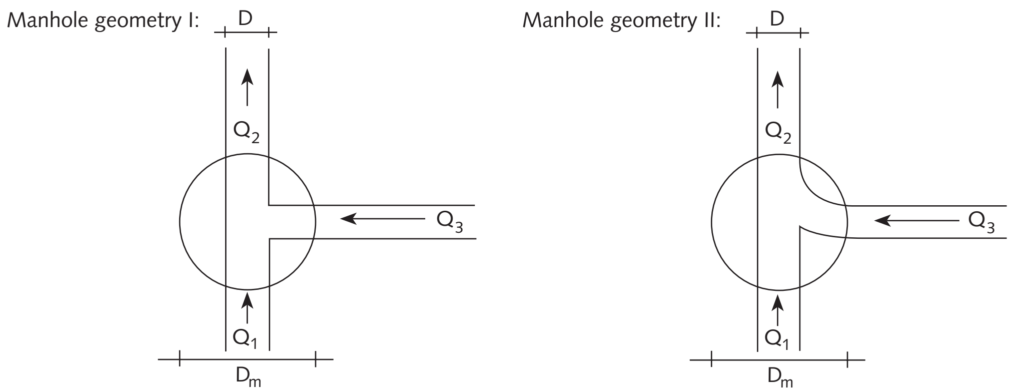


Figure 5.8 Two examples of manhole geometries tested in detail

ASSIGNMENT

Explain why a local loss coefficient can never exceed a value of 1.0.

Figure 5.9 Manhole head loss coefficient plots for geometry I in figure 5.8, in which a/D is the ratio between water level and pipe diameter, and Dm/D is the ratio between manhole diameter and pipe diameter.

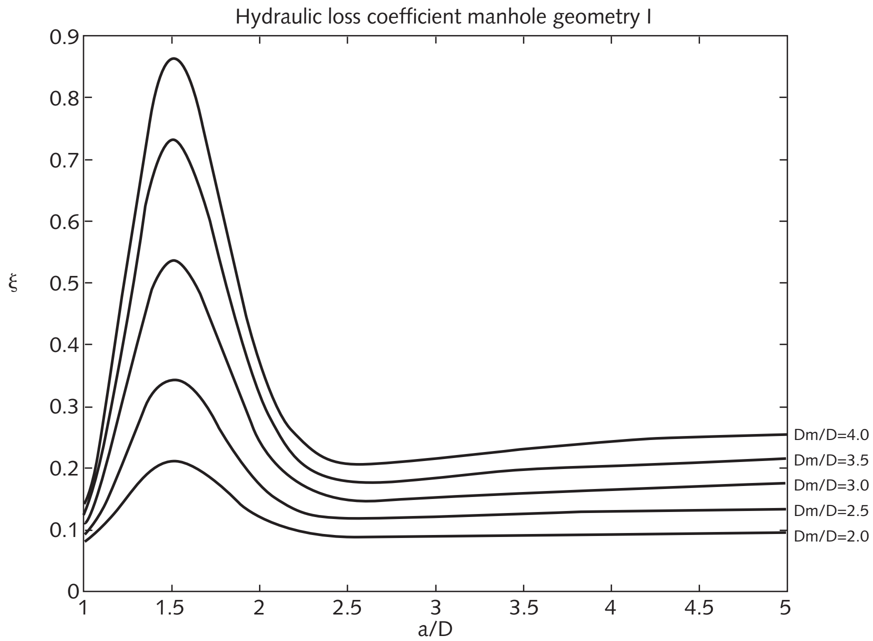
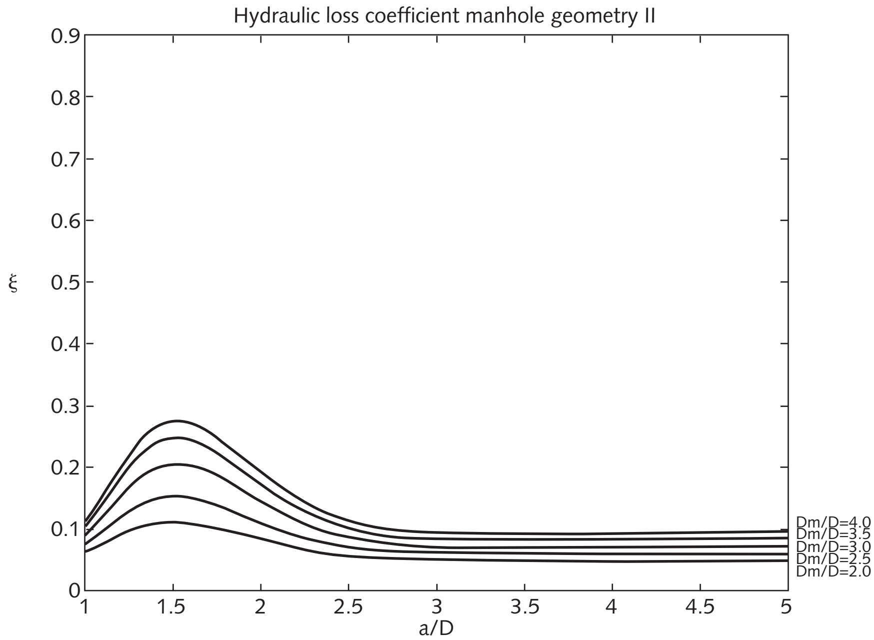


Figure 5.10 Manhole head loss coefficient plots for geometry I in figure 5.8.



As these figures clearly show, the head loss coefficient is anything but constant, being closely related to the filling level. If a design calls for an exact knowledge of the loss coefficient value, either a scale model test must be carried out, or the designer can search to see whether the structure has already been described in one of the existing detailed table compilations. One of the most popular reference works in this respect is IdelChik (2001).

5.4.2 Sediment transport

It is inevitable that sediments will end up in the sewer system (for example sand and other material that is carried into the system by runoff from roads). The composition of sediment in the sewer system can vary greatly according to place and time. In Dutch sewer systems, the general lack of depth to accommodate sufficient sole level gradients makes it practically impossible to create self-cleansing conditions, and consequently layers of solids will always be encountered in the sewer system. In the past decennia much international research[1] has been conducted on sewer sediments, because they form a major source of problems, as listed below.

- Sediments reduce the transport capacity of the sewer system.
- Sediments form a reservoir of pollutants that may become dislodged during rainfall and subsequently discharged through overflows.
- The presence of sediment may contribute to the forming of corrosive materials.

All in all sufficient reason to take a closer look a sewer sediment. Sewer sediment can range from granular material (e.g. sand) to a thick kind of liquid, and any possible combination between these two extremes. Where a thick liquid is present, density flows occur (rather like the interactions that take place between salt and sweet water in estuaries). In times of rainfall this type of material will be transported in the form of a suspension.

For granular material (in particular sand) practical research on the morphology of coastal and river reaches has produced a variety of relationships between flow rate/shear stress, sediment properties, and the geometry of the problem. Further research (Kleywegt 1992) has shown that these formulae cannot simply be applied to the sewerage context as they are, because

- the geometry of a pipe is not like that of a river;
- the flow patterns in a pipe differ from those in a river;
- the sediment in a pipe can become exhausted;
- the properties of sewer sludge vary widely.

All this means that the well-known morphology formulae cannot and may not be applied to sewerage problems.

A recent doctoral thesis (Schellart 2007) produced the conclusion that with the current level of knowledge it is impossible to come to practical predictions about the transport of sediment. What is possible though, is to predict locations where sedimentation will occur.

In situations in which calculations on sediment transport are impractical, the following options are available.

- Preventing unnecessary sedimentation by adapting the design and construction accordingly.
- Maintaining a focused cleaning policy.

The following are ways in which sewerage designs can take sediment into account.

- Avoid creating locations in which stagnant or near stagnant pools of water can form during dry weather conditions.
- Ensure that the water depth during dry weather conditions does not remain less than 10 cm for extended periods in order to prevent floating material collecting, disintegrating and forming a cohesive sediment layer.

1 *The IWA (International Water Association) in 2004 published a book summarising the research results of the past 20 years. (Eds. R.M.Ashley, J.-L. Bertrand-Krajewski, T.Hvitved-Jacobsen, M.Verbanck.), Scientific and Technical Report No. 4, IWA Publishing.*

5.4.3 Overflows and sewer pumping installations

Overflows

Overflows can be considered as short perfect spillways. The flow rate across the overflow can be calculated from:

$$Q_o = mBh^{\frac{3}{2}} \tag{5.12}$$

in which

h = height of the overflow radius, in m

Q_o = flow rate over the overflow, in m^3/s

m = runoff coefficient, in $m^{1/2}/s$

B = length of the overflow edge (weir), in m

It should be noted that the runoff coefficient, m, contains the square root of the gravitational field *g*, which explains its SI unit of $m^{1/2}/s$. Strictly speaking h should be replaced with H, the energy height, but for practical use H is approximately equal to h. In most cases it is advisable to choose m equal to 1.5. Generally speaking the height of the overflow edge (weir level) will be constructed so it is above the water level of the surface water into which the overflow discharges. In practical situations however, conditions can result in a submerged weir (also known as a dammed or imperfect weir). Calculations to check the proper operational qualities of existing systems should take this into account.

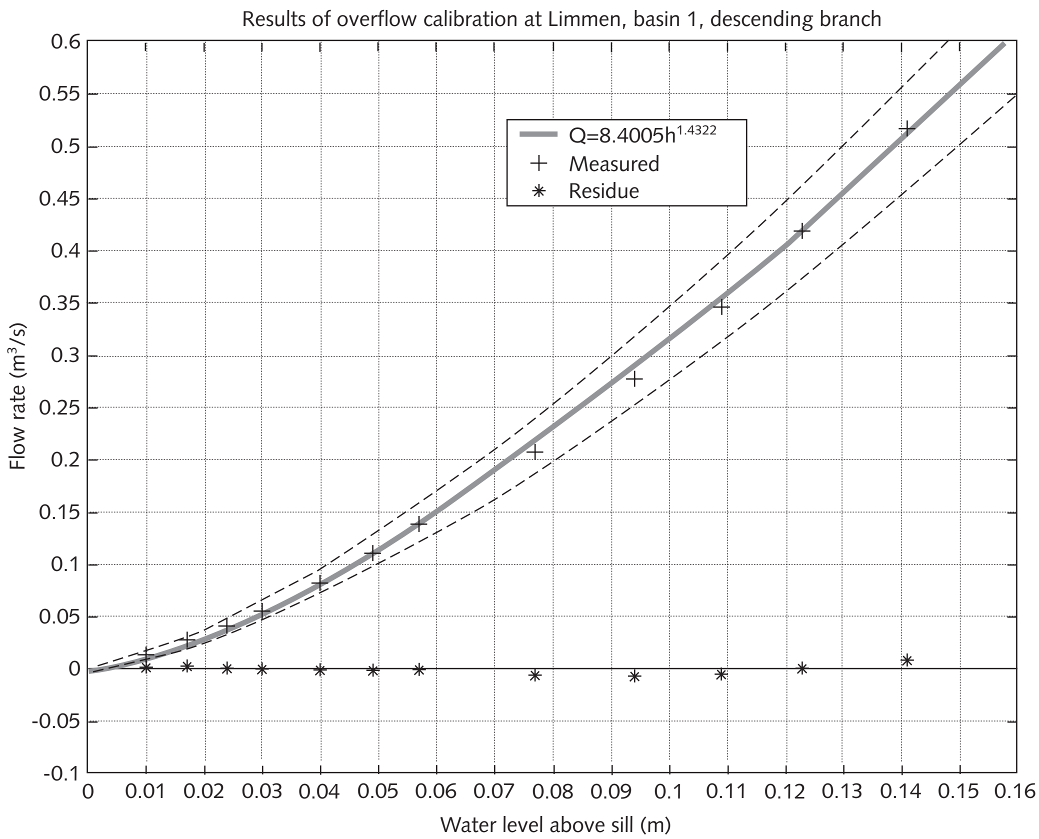


Figure 5.11 Measured Q-H relationship of an overflow. The red line indicates the Q-H relationship of the overflow; the dotted lines indicate 95% reliability interval (i.e. for a certain value of the water level there is a 95% probability that the value of the flow rate lies within that delimited range).

If for whatever reason it is important to have highly accurate relationship figures between the water level, h, and the overflow rate, an in-situ calibration must be performed. Figure 5.11 shows the result of such a calibration. As the figure shows, the measured results do not match the theory, in particular for smaller flow rates. This is to do with the way the water flows into the overflow edge.

The deviations from the standard formula increase as the flow rates decrease. Table 5.6 provides some values.

Table 5.6 Overflow calibration chart, Limmen.

Overflow height, m	**Q (calibration), m³/h**	**Q (standard), m³/h**	**Deviation, %**
0.02	111.5	94.7	-15.0
0.05	414	374	-9.7
0.10	1118	1059	-5.3
0.24	3917	3936	+0.5

Pumping installations

Sewer pumping installations contain the pumps that pump away the collected wastewater. Historically, pumps were switched using maximum and minimum level switches. These were adjusted to ensure that a pump would not be switched on more than 4 to 5 times an hour in order to prevent damage to the pump motors from being switched on too frequently. Such a switching regime demands a certain storage capacity within the sewer pumping installations, known as the hysteresis storage capacity (wet well). The hysteresis storage capacity, i.e. the volume that needs to be accommodated between the two levels at which the pump is switched on and off, can be calculated as follows.

$$V_p = \frac{0.9 Q_p}{s} \tag{5.13}$$

in which

V_p = hysteresis storage capacity in m³

Q_p = pump capacity in l/s

A = number of switching cycles per hour

Example: What is the required surface area of a pump basin for a pumping capacity of 100 l/s, a maximum switch cycle of 5 per hour, and a difference between switching levels of 0.3 m?

The required hysteresis storage capacity is $V_p = \frac{0.9 * 100}{5} = 18 m^3$

therefore the surface of the pump basin needs to be 18/0.3 = 60 m².

Small sewer pumping installations still use level-operated switching pumps, but most sewer pumping installations these days use adjustable-speed pumps that adjust their pumping capacity to the incoming flow of wastewater, thus ensuring that the water level within the sewer pumping installation remains practically constant. As a result the pumps are kept running continuously and no longer need to be switched on and off.

The design of pump basins merits special attention, since the submerged suction end of the pump must not come close enough to the water surface to create a vortex. A vortex can lead to air being sucked into the pressure pipeline, which can ultimately cause the discharge of water to become practically impossible. The detailed design of pumping installation basins is a specialist job and so it will not be discussed further in this context. We will note however that the Delft University of

Technology (TU Delft) and the Delft Hydraulics Laboratory (WL Delft) have been engaged in the CAPWat (capacity of wastewater pressure pipes) research programme since 2003, investigating the formation and effects of gas pockets in pressure pipes (see also Lubbers 2007, and www.wldelft.nl/rnd/intro/topic/2004-capwat).

5.5 Calculations

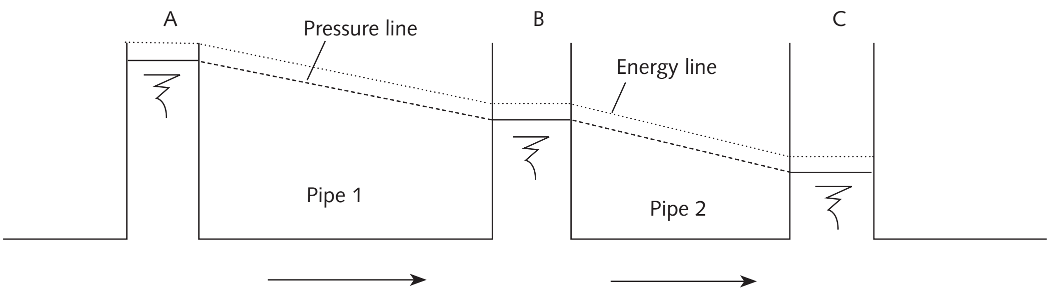
5.5.1 Manual

Dendritic systems

Dendritic (tree-like) sewer systems, in which the direction and rate of flow are both determined in advance, can be calculated manually. Making a hydraulic calculation for a dendritic system involves the following steps.

- Determine where the system discharges into surface water.
- Determine the impervious surface catchment area of the sewer system from existing drawings or by taking measurements.
- Determine the representative precipitation load. In the Netherlands a constant precipitation intensity of 60 litres per second per hectare, or on slopes 90 litres per second per hectare, is normally assumed.
- Determine the runoff into the separate pipelines. The flow rate in the most downstream pipeline is equal to the sum of the flow rates in all the upstream pipelines.
- Estimate the diameters of the pipes, assuming a flow rate of 1 m/s in all pipes, a k value of 1 mm, and completely filled pipes.
- Determine the drop, which in this case is equal to the resistance loss along the length of the pipeline. The drop can be calculated by means of the formulae listed in section 5.4. Based on a certain pressure head in manhole A the calculated drop along pipeline 1 can be used to determine the pressure head in manhole B.

Figure 5.12 Schematic diagram of the discharge through pipes 1 and 2.



The drop along pipeline 2 can then be calculated based on the sum of the flow rates discharging into pipeline 2 (see figure 5.12). These drops are then added to the drop along pipeline 1. The procedure can then be repeated until the pressure heads have been determined for every node in the network.

Check to make sure the pressure heads satisfy the requirements. If the resulting water level lies within the pipeline, or if it rises above ground level, the diameters of the pipes must be changed accordingly and the calculation repeated.

Looped systems

In a looped sewer system it is impossible to tell what the flow and flow rate distribution throughout the system will be. The water can pass along different routes, and the final distribution depends on the energy losses that occur in the flow. Put simply, the water will take the easiest route.

Unlike a dendritic system, a looped system even makes it impossible to say in which direction the water in any section of pipe will flow. It is also far from clear how the water will become distributed within each section of the grid. Performing manual calculations on large looped networks is impractical, which is why computer programmes are used for this purpose.

5.5.2 Computer – hydrodynamic calculation

Computer programs for non-stationary hydraulic calculations have been in use since the mid-1990s. These were based on the De Saint-Venant equations, better known as long-wave equations. These make it possible to obtain a reasonably accurate impression of way the changing water levels in all the manholes and the changing flow rates in all the pipes in a sewer system.

It is possible to make these models match real-life conditions quite closely by calibrating them with experimental readings, provided that the correct calculation parameters are used.

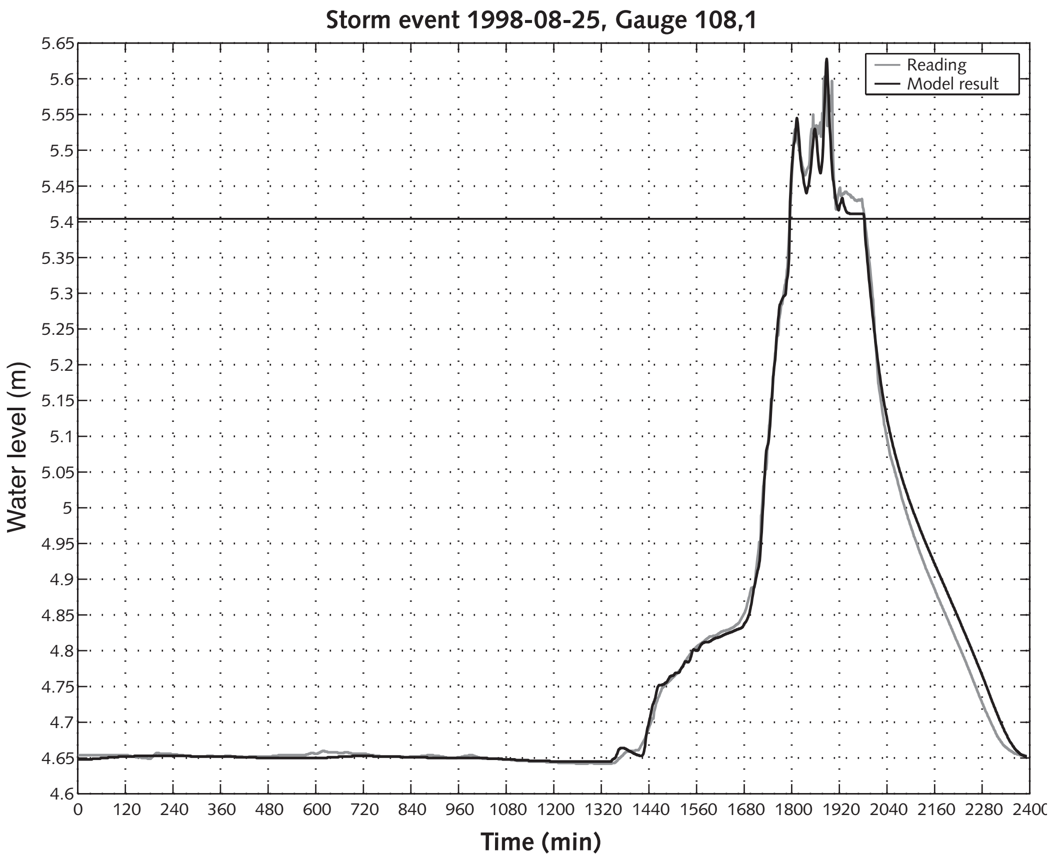
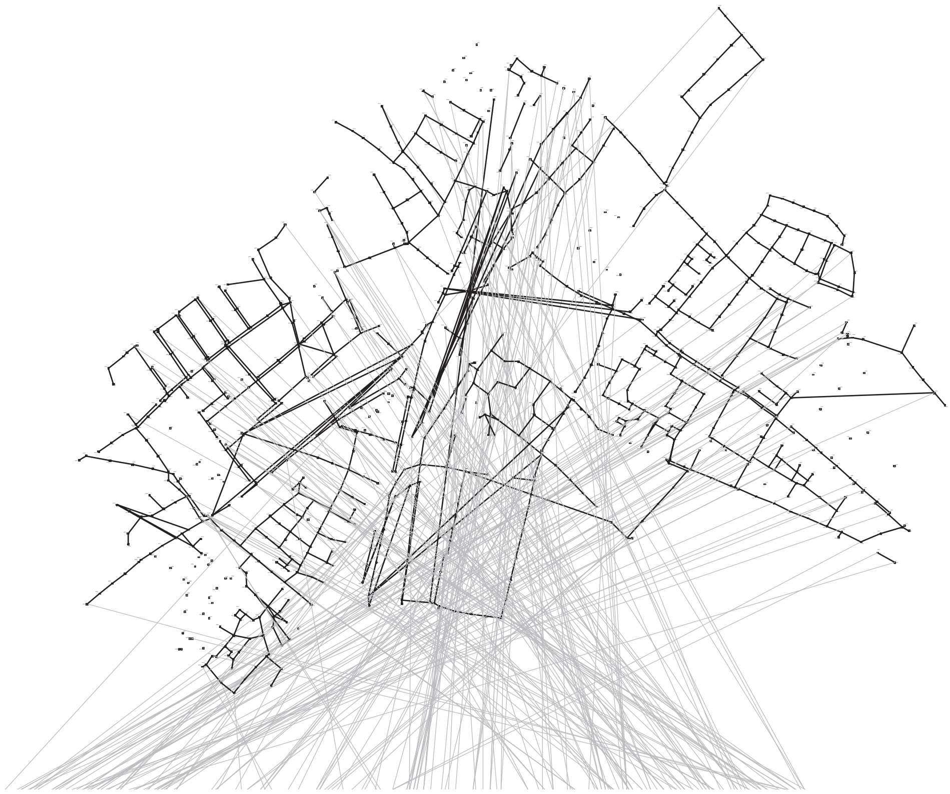


Figure 5.13 Example of the result of a model calibration (source: Clemens 2001).

As discussed in section 5.1.3, hydrodynamic calculations use what is known as a full sewer model, which puts very high demands on the quality of the input data. In the real world these often form a source of errors. Figure 5.14 shows an example of a database that still contains 'a few errors'. It will be evident that it is a waste of time to use such a collection of data for calculations.

Figure 5.14 'A modeller's nightmare' (source: Clemens 2001)



5.5.3 Urban Drainage Guideline – Module C 2100

In 1995 a module C2100, 'hydraulic performance sewerage calculations' (*rioleringsberekeningen hydraulisch functioneren*) was added to the Urban Drainage Guideline. The module describes in detail how a hydrodynamic calculation of a sewer system should be performed and reported. It is based on a process description, so the user is free to choose his preferred tools (i.e. computer program). This has the added benefit that, unlike a system that prescribes the use of a certain calculation package, the current method does not hinder the continued development of calculation techniques.

The module provides default-values for model parameters (e.g. the roughness of pipe walls, and the overflow coefficient). In addition the module provides the following.

- Methods for calculating the catchment surface area.
- Methods for allocating the catchment areas to components of the sewer system.
- Standard precipitation loads (standard design storms with different recurrence times and a standard precipitation sequence).
- Information exchange formats for calculation databases and results, allowing for software-independent methods.

Making calculations in accordance with module C2100 is a specialist job. Provided it is performed correctly, it offers the following advantages over the simpler methods discusses earlier in this chapter.

It produces a highly detailed view of the hydrodynamic behaviour of the sewer system.
The model results can be checked against real-world readings (which was impossible using stationary calculations, as the real world is not static).

It is good at visualising dynamic effects, such as waves of wastewater that amplify or attenuate each other. It makes it easier to understand issues that a stationary view cannot clarify.

5.5.4 Hydraulic performance calculation

In the event of extreme precipitation it is practically impossible to avoid some flood problems. As the flow of water into the sewer system increases, it reaches a point when the system can no longer discharge the wastewater into surface waters. However, there is no fixed definition of what constitutes a flood problem, and consequently flood problem conditions cannot be calculated. What can be calculated is the water pressure inside the sewer system. Once the pressure head rises above ground level for a given precipitation load, the water will emerge through every available opening (starting with roadside gullies) to flood the surface[2]. This is known as flooding. Figure 5.15 shows an example of a flooding calculation result.

Every Municipal Sewerage Plan states the number of times it is 'acceptable' for water to flow out of the system in this way. RIONED Foundation published a memo in 2006 (see www.rioned.org) which states that in general once every two years is accepted as the minimum recurrence time.

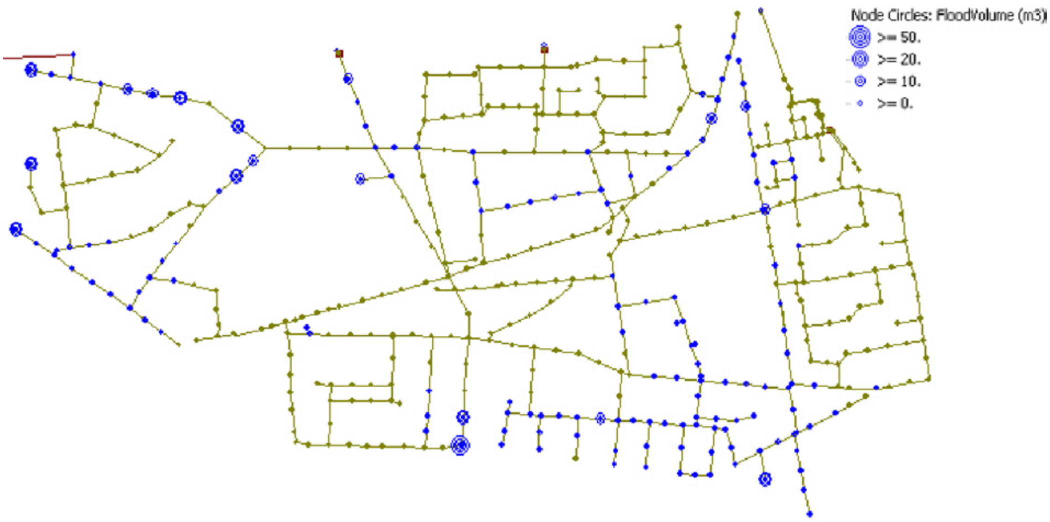


Figure 5.15 Sample results of a flooding calculation (shower 08, T = 2 years). The blue circles show the location and give an indication of the severity of the flooding problem.

Checking flooding calculations

Flooding calculations are checked as follows.

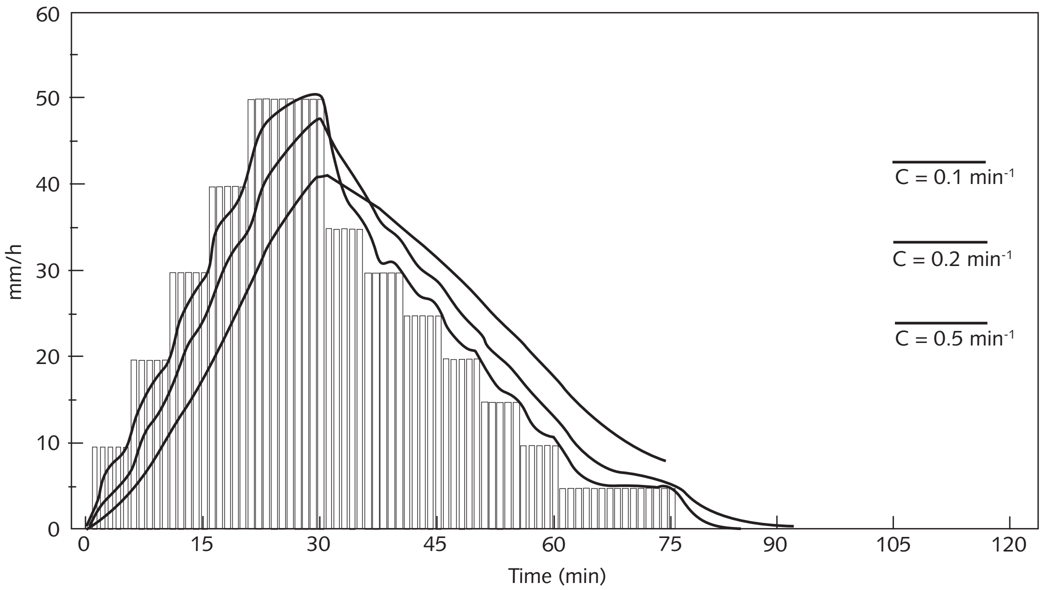
1. Compare the flooding locations in the model with the observed problem locations.
2. The depth of the flooding in the calculations may not exceed 15 – 20 centimetres. If it does, the calculation probably contains an error:
   - the ground level has not been entered correctly in the model;
   - the surface on which the water can be retained has not been entered correctly.
3. The volume of flood water may not be too large. This occurs in particular for incorrect ground level values, possibly in combination with a large continuous impervious surface.
4. Flooding should not occur close to an overflow. If this is the case, the model may contain an error such as:
   - an overflow has been 'closed off';
   - The diameters of the pipes in between is incorrect (too tight).
5. If no flooding occurs, but there are flooding complaints, the calculation contains an error. This should always be looked into. Possible errors include:
   - An incorrect inflow model or an incorrect shower was used;
   - Incorrect friction in the pipes, or incorrect pipeline length or width (e.g. meter sizes were entered as millimetres);
   - Incorrect ground level value entered (typo in the database).

2 If there is nowhere for the water to escape to, the pressure will increase to the point where the water will have sufficient force to lift even manhole covers.

As mentioned before, stationary calculations in level areas are based on a precipitation load of 60 litres per second per hectare, and in areas on an incline a value of 90 litres per second per hectare is used. On a slope there is always the risk of flood water flowing to the lowest locations, potentially resulting in higher water levels and causing greater damage in lower-lying areas.

For hydrodynamic calculations (in accordance with the Urban Drainage Guideline module C2100) standard design storms are normally used. C2100 includes a list of 10 design storms with precipitation intensities that vary over time. These design storms were derived from the standard precipitation sequence for 1955 – 1979 as observed by the Royal Dutch Meteorological Institute at De Bilt. Each of these design storms is linked to a recurrence time. Now if design storm no. 08 (with a recurrence time of 2 years) causes flooding at some point, this does not mean that the recurrence time of this phenomenon is the same as the recurrence time of the selected design storm. The non-linear nature of a sewer system prevents us from simply translating the statistic properties of the load (the standard shower) into model results as they are.

Figure 5.16 One of the standard design storms from Urban Drainage Guideline module C2100 with a recurrence time of 4 times a year.



5.5.5 Environmental performance calculation

For reasons of economy, sewer systems include outlets or overflows. Overflows forming part of combined sewer systems merit particular attention, since any overflows contain untreated wastewater and will therefore adversely affect the surface water quality. Over the years, the requirements for sewer systems regarding the discharge of wastewater into surface waters have changed as follows.

- Requirements regarding the dilution of foul water with precipitation, until roughly 1950.
- Admissible overflow frequency (from roughly 1950 until the early 1990s).
- Basic effort requirement (current).

The latter two standards will be discussed here, as they are still of current interest.

Overflow frequency

The overflow frequency was subject to certain conditions imposed by the water quality management authorities. These conditions used the theoretical average annual overflow frequency as a measure. In 1951 Ribius [Ribius, 1951] published an article in which he introduced the overflow frequency as a criterion for comparing combined systems with each other. The reason for this was that he wanted to get rid of the dilution theory that was current at the time. The gist of this theory was that as soon as the wastewater flow had been diluted 5 to 10 times by runoff, overflows were allowed to open.

Each day, each individual in the Netherlands discharges about 135 litres (these days that would be about 120 l) into the sewer system. For purposes of dimensioning the system, it is assumed that this volume will be disposed of over a period of 10 hours. The impervious runoff surface measures approximately 50 m^2 per person. Therefore the discharge equals 0.75 litres per second per hectare. Assuming that the dilution factor is to be 10, this means that overflows may not spring into action before the precipitation intensity reaches 7.5 litres per second per hectare. The sill levels in the systems were designed to enable the system to cope with a flow rate of up to 7.5 litres per second per hectare.

However, a water treatment plant could only cope with a flow rate of 2 to 4 times the foul water flow. Based on the figures given above, this results in a flow rate of 1.5 to 3.0 litres per second per hectare. This meant that the dilution factor at an overflow near a sewer pumping installation would be only 2 to 4 instead of 10.

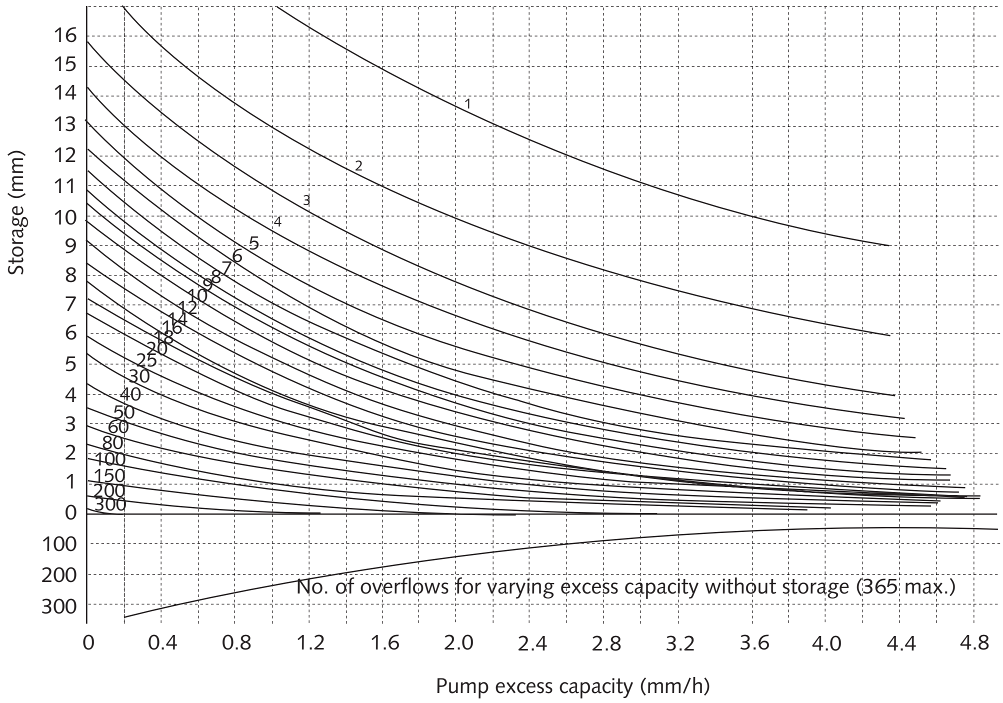
Ribius proposed a simple model for calculating the overflow frequency of combined sewer systems. He regarded a combined sewer system as a basin that became filled by rain and was emptied by means of the pumps in the sewer pumping installation.

The processing capacity of the pumping installation is approximately 2 to 4 times the foul water flow rate. Any rainfall with an intensity less than 1 to 3 times the foul water flow (wastewater still enters the system during periods a rain) did not cause the basin to fill. Any higher intensity, assuming that the basin became filled to capacity, would result in an overflow. In order to calculate the theoretical overflow frequency for a certain period, precipitation figures needed to be available. Kuipers had analysed, also in 1951, the rainfall readings obtained by the Royal Dutch Meteorological Institute at De Bilt during the period stretching from 1938 up to and including 1949.

The calculation of the overflow frequency is based on three figures describing future conditions:
- The impervious surface of roads and roofs (F_v in ha)
- The available storage capacity in the sewer system (B in m^3)
- The available discharge capacity (Q in m^3/h)

Based on the method indicated by Ribius and using the precipitation data collected by Kuipers, F.B. Veldkamp drew up a diagram that gave a direct value for the overflow frequency for any given storage capacity and excess pumping capacity. The diagram was based on the precipitation data for the 1938 – 1949 period. In 1963 Veldkamp modified the diagram based on the precipitation readings for the 1926 – 1962 period. In 1969 the diagram was extended by including the design storms with a precipitation reading of less than 4 mm. This is the diagram shown in figure 5.16, which is still used today for the calculation of overflow frequencies. For a given storage capacity and excess pumping capacity, the overflow frequency can also be calculated using the so-called Veldkamp diagram, see figure 5.17.

Figure 5.17 The Veldkamp diagram



Example 1

The lower sill storage capacity is 800 m³. The impervious surface is 10 ha. Therefore the storage capacity is 80 m³/ha = 8 mm. The excess pumping capacity is 80 m³/h. Therefore q_{epc} *is 8 m³/(h × ha) = 0.8 mm/h. The Veldkamp diagram shows an average overflow frequency of 6 to 7 times a year.*

Example 2

A sewer pumping installation has a capacity of 700 m³/h. The foul water flow is 250 m³/h. Therefore the excess pumping capacity is 700 - 250 = 450 m³/h. The storage capacity is 9 mm. The impervious surface area is 150 ha. The foul water flow is 125 litres per person per day. Therefore:

q_{epc} *is 450 / (150 × 10) = 0.3 mm/h. The Veldkamp diagram shows an average overflow frequency of 9 times a year. The storage capacity is 9 × 10 × 150 = 13,500 m³. The number of inhabitants is: 250 / (125 / (10 × 1,000)) = 20,000. The impervious surface area per person is 150 × 104 / 20,000 = 75 m².*

Example 3

In a new urban development plan the impervious runoff surface has been estimated at 10 ha. The area will have a combined sewer system. An analysis of the Sewerage Plan shows that the lower sill storage capacity will be 700 m³. The average overflow frequency is to be 10 times a year. Therefore:

The storage capacity is 700 / (10 × 10) = 7 mm. The Veldkamp diagram shows that the excess pumping capacity will have to be 0.7 mm/h, i.e. 7 m³/(h × ha). Therefore an excess pumping capacity needs to be installed of 7 × 10 = 70 m³/h. The impervious surface area is 50 m²/ inhabitant. This puts the number of inhabitants at 10 × 10,000 / 50 = 2,000. We shall assume a value for Q_{foul} *of 120 litres per person per day. Therefore* Q_p *equals (120 × 2,000) / (10 × 1,000) + 70 = 94 m³/h.*

Basic effort
In the mid-1980s the Netherlands ratified an international effort aimed at reducing the discharges into surface water from diffuse sources by 50% within 10 years. This target is laid down in the so-called RAP-NAP resolutions, in which 1985 is set as the reference year. Therefore the reduction was to be completed by 1995. The conversion into actual policy in the Netherlands went as follows. The reduction target was included in the provincial Water Management Plans from which, by means of a deputised authority, the water quality management authorities (i.e. the water boards) were given the task to realise the proposed reduction using the permit system within the Surface waters pollution act. A problem that transpired during the early stages of this operation was the fact that in most cases it was, and remained, practically impossible to quantify the discharge situation as it was in 1985. An especially complex case within this context was formed by the discharges from sewer overflows. When the policy was instigated the exact number of overflows was unknown, as were their locations and the quantities of foul water discharged. It was considered impractical to launch a nation-wide survey, so a pragmatic approach was introduced by the CUWVO-VI study group (*Commissie Uitvoering Wet Verontreiniging Oppervlaktewater,* surface water pollution act executive committee). This entailed the following.

The 1985 the foul water discharge was assumed to be equal to the foul water discharge from a notional combined sewer system that complied with the then current standard of an average of 10 overflows a year. The standard was met by a notional sewer system with a storage capacity of 7 mm and sufficient pump capacity to move the foul water and the 0.7 mm/ha excess pumping capacity. In such a notional system a foul water discharge reduction of 50% could be effected by creating an additional storage capacity of 2 mm in a storage/settling basin.

Some water management authorities have subsequently interpreted this to mean that the sewer system needed a minimum storage capacity of 7 mm, plus an extra storage capacity of 2 mm in a peripheral facility, and a minimum excess pumping capacity of 0.7 mm/ha in order to comply with the basic effort requirement. This interpretation is incorrect, since the CUWVO-VI study group standard states that the existing combined sewer systems must be modified in order to ensure that the foul water discharge from the system will be no more than the foul water discharge from a notional sewer system with a storage capacity of 7 mm, an additional storage capacity of 2 mm in a peripheral facility, and 0.7 mm/ha excess pumping capacity.

The basic effort requirement for combined systems is usually defined as a maximum admissible annual average percentage of the total precipitation. A precipitation sequence is then used to calculate how many mm of the precipitation on average would have been discharged by a notional system with a storage capacity of 9 mm (7 mm in the system and 2 mm in a storage/settling facility) and an excess pumping capacity of 0.7 mm/h. Individual water quality management authorities can impose additional standards, e.g. with regard to peak discharges (recurrence times of 1, 2, 5, and 10 years).

Nowadays the discharges are calculated by means of a hydrodynamic model loaded with a historic precipitation sequence (the standard sequence from the Urban Drainage Guideline module C2100 observed during the 1955-1979 period at De Bilt). For each individual overflow this can provide detailed information about:
- The number of overflows.
- The volume per overflow.
- The duration of the overflow.

This makes it possible to see whether a certain overflow can become a problem (in quality or quantity) for the receiving surface water, and allows the most effective countermeasure to be determined for each individual overflow. Stationary calculations do not offer such refined options, or if they do, in a minor way only.

5.5.6 Wastewater system calculations

The sewer system forms part of the total wastewater system. Generally speaking several gravity systems and pressure systems connect through pumping installations and pumps to a system of pressure pipes that discharge into a water treatment plant. The treatment efficiency of a water treatment plant depends on the quantity (and the fluctuations in that quantity) and composition of the wastewater it receives. Since the mid-1990s closer attention has been paid to the performance of the wastewater system as a whole, by means of a wastewater system optimisation (*Optimalisatie Afvalwatersysteem, OAS*). This can be used to achieve various objectives:

- Using the available means (sewer system, pumping installations, pressure pipes, water treatment plant), minimise the foul water discharge of the entire system.
- Maintaining the present performance, minimise the cost (both cost of investment and operational cost).
- Special objectives related to e.g. surface water quality (such as reducing the impact on certain ecologically important waters).

Many cases have shown that an approach at wastewater system level results in better and cheaper solutions than in the situation in which, within the set standards, a design or certain form of operational management is deployed for each component separately. The underlying calculations of a wastewater system optimisation cover the hydraulic performance of the sewer systems, the pumping installations and pressure pipes, as well as that of the water treatment plant. This means that teams of specialists are usually involved for each of the separate fields.

Self-assessment questions for chapter 5:

1. Give a short description or definition of the following quantities, including the SI unit in which each unit is normally expressed.
   • The impervious surface
   • The runoff coefficient
   • The storage capacity in a sewer system
   • The time to empty
   • The excess pumping capacity
   • The foul water flow
   • The precipitation intensity
2. A sewerage catchment area has a total surface of 0.5 km². Of this total, 45% is impervious surface. Within this area lies a total of 15 km of sewer pipe with an average diameter of D = 400 mm. These sewer pipes are all beneath the overflow level. For this area, calculate the impervious surface area in hectares, the storage capacity in m³, and the storage capacity in mm.
3. For the area in question 2, calculate the required excess pumping capacity if the time to empty of the sewer system is specified as 20 hours.
4. The area of question 2 is populated by 3750 people in 1900 houses. Calculate the foul water flow from this area, in m³/h, in mm/h, and in mm/year, assuming a peak discharge of 12 l/h per person, and an average discharge of 5 l/h per person.
5. For the same area, calculate the ratio of the excess pumping capacity relative to the required foul water capacity.
6. Calculate the shear stress for a half-filled wastewater sewer with D = 300 mm, given that the sewer has been laid at a pipe gradient of i_b = 1/300 and that a state of flow equilibrium exists in the pipe.
7. Calculate the rain intensity in mm/h for a continuous rain intensity of 90 l/(s × h) (impervious surface). Using the rain duration lines, estimate how often this rain intensity is to be expected during design storms lasting 1 hour, 4 hours, and 24 hours.
8. Using the rain intensity from question 2, calculate the flow rate, in m³/h, for the low entering the sewer in the area from question 2.
9. What are the main criteria to determine which type to select for a new sewer system?
10. For a completely filled pipeline with D = 300 mm and a wall roughness of k = 1.5 mm, calculate the loss of energy due to friction along a pipeline length of 50 m at an average velocity of 1.5 m/s.
11. This time the pipeline from question 10 is half-filled and in a state of flow equilibrium, in which $i_e = i_b$ = 1/300. Calculate the average velocity and the flow rate through the pipeline.
12. Calculate the water level h required to produce an overflow rate of 300 m³/h, given an unobstructed short overflow with a width of B = 2.6 m and a runoff coefficient m = 1.5 $m^{1/2}$/s.
13. What does 'water on road' mean? Should this be prevented at any time, or is it acceptable in certain conditions? If it is acceptable, what are the conditions that make it acceptable?
14. In a combined sewer system, the storage capacity is B = 8.75 mm. The total capacity of the sewer pumping installation is 143.4 m³/h, and the foul water flow rate is 45 m³/h. The impervious surface area is 22.5 ha. Using the Veldkamp diagram, calculate the overflow frequency of this system.
15. What does it mean to comply with the basic effort requirement?
16. Does the system from question 14 comply with the basic effort requirement?

References

Bouwknegt, J. and A.J. Gelok
Regenduurlijnen voor het ontwerp en beheer van waterbeheersings- en rioleringsprojecten. Heidemij Adviesbureau, Landinrichtingsdienst

Clemens, F.H.L.R. (2001)
Hydrodynamic models in urban drainage: application and calibration. Doctoral thesis, Delft University of technology. ISBN 90-407-216-7.

CUWVO Werkgroep VI
Overstortingen uit rioolstelsels en regenwaterlozingen, aanbevelingen voor het beleid en de permitverlening, April 1992.

IdelChik, I.E. (2001)
Handbook of hydraulic resistance, third edition. ISBN 978-1567000740.

Kleijwegt, R.A. (1992)
On sediment transport in circular sewers with non-cohesive deposits.
Doctoral thesis, TU Delft, 1992.

Langeveld, J.G. (2004)
Interactions within wastewater systems. Doctoral thesis, Delft University of technology.
ISBN 90-77595-72-4.

Lubbers, C. L. (2007)
On gas pockets in wastewater pressure mains and their effect on hydraulic performance. Doctoral thesis, Delft University of technology. ISBN 978-1-5860-789-5.

Van Mameren H.J. and Clemens F.H.L.R. (1993)
Het CUWVO-VI stelsel in de praktijk. H_2O (2) pp. 692-695.

Ribius, F.J. (1951)
Waterverontreiniging door regenoverstorten. Publieke Werken, no. 19, 1951.

Schellart, A.N.A. (2007)
Analysis of uncertainty in the sewer sediment transport predictions used for sewer management purposes. Ph.D. thesis, University of Sheffield, UK, April 2007.

Veldkamp, R. & Clemens F.H.L.R. (2001)
Het kalibreren van overstorten, Rioleringswetenschap no. 2, pp. 51-74.

6 Design and construction of sewerage

This chapter shows how to design and construct sewerage and how to use the various sewerage components to ensure that the finished sewer system performs as designed.

Section 6.1 looks at the most common components of sewerage. Next, section 6.2 show how to go about designing a sewer system, and provides some insight into the forces that act on sewer piping. The last section of the chapter, section 6.3, discusses the construction of sewer systems, looking at the construction techniques and the issues related to the construction of sewer systems.

This chapter does not discuss the cost aspects involved in the design and realisation of sewer systems. The Urban Drainage Guideline published by the RIONED Foundation includes the module D1100, Key cost figures for sewerage management (*Kostenkengetallen rioleringszorg*). Readers are encouraged to refer to this module to gain insight into the cost of the various components, the design, and the construction of sewer systems.

6.1 Sewerage components

Sewerage is the generic term for the coherent collection of sewer pipes, manholes, and other facilities used for the collection and transport of foul water and/or rainwater. An actual sewer system itself includes various objects with their own specific collection- and transport-related functions. A sewer system also contains other components with specific functions to ensure that the sewer system as a whole can perform as designed, minimising the impact on the population and the environment. A sewer system includes the following components:

- Sewers (interconnected pipes) and manholes. Each length of sewer piping between two manholes is known as a section (Dutch: *streng*).
- Domestic drains and road gullies that discharge the wastewater and runoff from the connected properties, sites, and roads into the sewer sections.
- Storage and storage/settling facilities that together with the overflows minimise the impact on the population and the environment.
- Sewer pumping installations that pump the sewage (wastewater) through the sewer systems and to the sewage treatment plant.

Nowadays, not all the wastewater is carried off by a closed sewer. Rainwater is discharged partially into surface water and partially into the soil, and eventually the groundwater.

The system to collect rainwater and transport it to the surface water uses the same closed sewer pipes and manholes. If the rainwater is to be drained into the soil, permeable pipes are needed that will allow the water to infiltrate into the surrounding soil. An assembly of these pipes is called an infiltration sewer (*IT-riool)*.

Sections 6.1.1 and 6.1.2 will discuss the components that make up a sewer section, i.e. sewer pipes and manholes. Sections 6.1.3 and 6.1.4 will look at the components that ensure that the wastewater can be discharged into the sewer sections, i.e. gullies and domestic drains. Next, section 6.1.5 will discuss the function of sewer pumping installations in sewer systems, and how they work. Section 6.1.6 takes a look at overflows. The overflows in combined sewer systems cause foul water to be discharged into surface waters. How and by means of which facilities we can minimise the foul water discharge into the surface water will be discussed in the next section, 6.1.7, on storage and storage/settling facilities in combined sewer systems. Section 6.1 closes with subsection 6.1.8, which discusses the types of pipes that are available for infiltrating rainwater into the soil, the so-called infiltration sewers.

6.1.1 Sewer pipes

Sewers are constructed using sewer pipes made of different materials. The most commonly used materials are:

- Concrete
- Plastic, the most common being polyvinyl chloride (PVC)
- Clayware

Each of these materials will now be discussed in some detail.

Concrete sewer pipes

Concrete pipes can be either circular or ovoid in section, and pipes can also have a flat base. In addition to these types of pipes there are pipes with a special shape that resembles the section of the ovoid pipes. The purpose of these pipes is to minimise the level of sedimentation inside the sewer system.

Up until the mid-1960s most of the pipes that were laid had a length of 1.00 m and featured ends with raised (male) and recessed (female) surrounds that interlocked and were sealed using a bituminous strip, bituminous caulking, or mortar. These techniques all suffered from the draw-back that uneven settling could cause the connections to become undone. This would cause leaks, with water flowing both into and out of the pipes. The roots of trees growing near the sewer would enter through the gaps, causing root blockage problems on a large scale. These pipes were either circular or ovoid in shape. In the late 1960s pipes began to be produced that used collared socket joints in combination with a rubber sealing ring. These had the advantage that in the event of uneven settling they remained watertight, provided the resulting deformation remained within certain limits. These pipes were initially produced in lengths of 2.00 m, but today the production length is 2.40 m.

Figure 6.1 Old type of pipe with male and female ends

Different types of concrete pipes exist. Which kind of pipe is used depends on the load that the pipes will be subjected to. The following options are available:
- Non-reinforced pipes in standard and heavy-duty types
- Reinforced pipes
- Steel-fibre concrete pipes

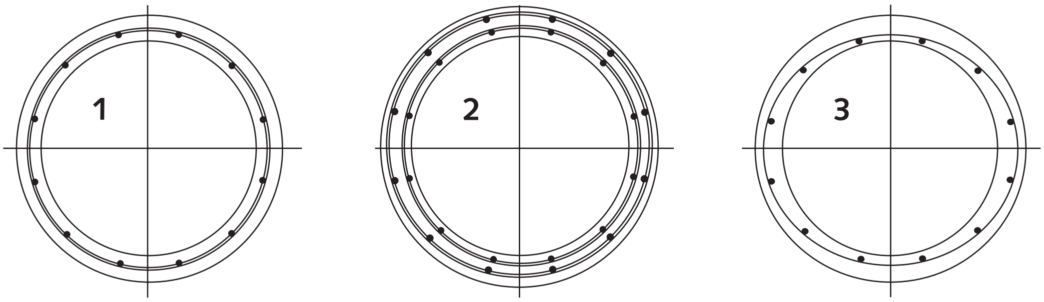


Figure 6.2 Concrete pipes featuring single (1), double (2), and oval (3) reinforcements

Reinforced concrete pipes can feature different types of reinforcements. The figure above illustrates three options for pipe reinforcement. Pipe no. 1 has a single reinforcement, pipe no. 2 features double cylindrical reinforcement nets, and pipe no. 3 shows a non-cylindrical (oval) reinforcement.

Figure 6.3 Concrete pipes with flat base (Betonplaza) and round concrete sewer pipes with socket joints

The rubber ring seal of the socket joint pipes comes in two distinct types:
- Sliding joint
- Rolling joint in profiled and non-profiled versions

The significant differences between both types are discussed below.

Sliding joint
The sliding joint is a profiled joint in which the spigot (male) end usually features a groove around the circumference of the pipe. The rubber ring is fitted into the groove, after which the ring and the front of the socket are coated with a lubricant before the joint is closed. The type of joint has the advantage that the rubber ring is always correctly located and requires little checking. The rubber rings can vary in shape, and often feature some kind of sealing strip. The drawbacks of this type of joint are the need to apply a lubricant and the fact that non-standard lengths need to be factory-supplied. See figure 6.4.

Figure 6.4 Sliding joint principle

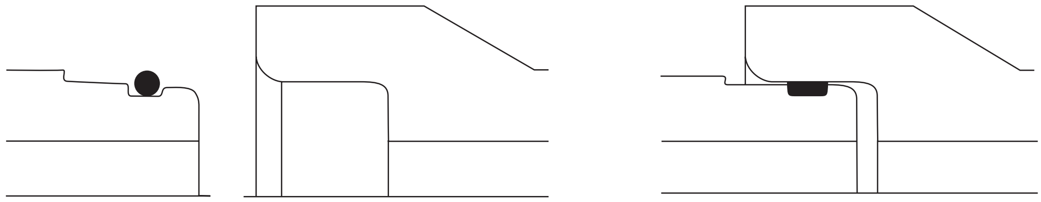
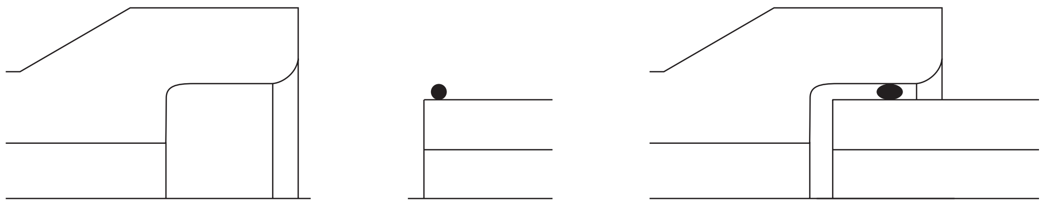


Figure 6.5 Factory-supplied non-standard pipe length with sliding joint. The male end on the right was cut to shape by the manufacturer.

Non-profiled rolling joint

In non-profiled rolling joints the male end is straight and has the same diameter as the outside of the pipe. The section of the rubber ring is oval in shape. The advantage of this type of joint is that non-standard lengths can be prepared in situ.

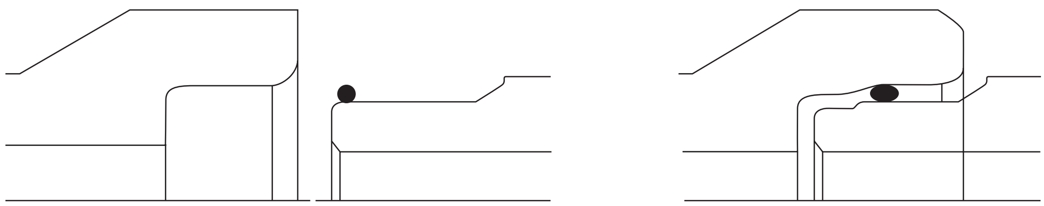
Figure 6.6 Non-profiled rolling joint principle.



Profiled rolling joint

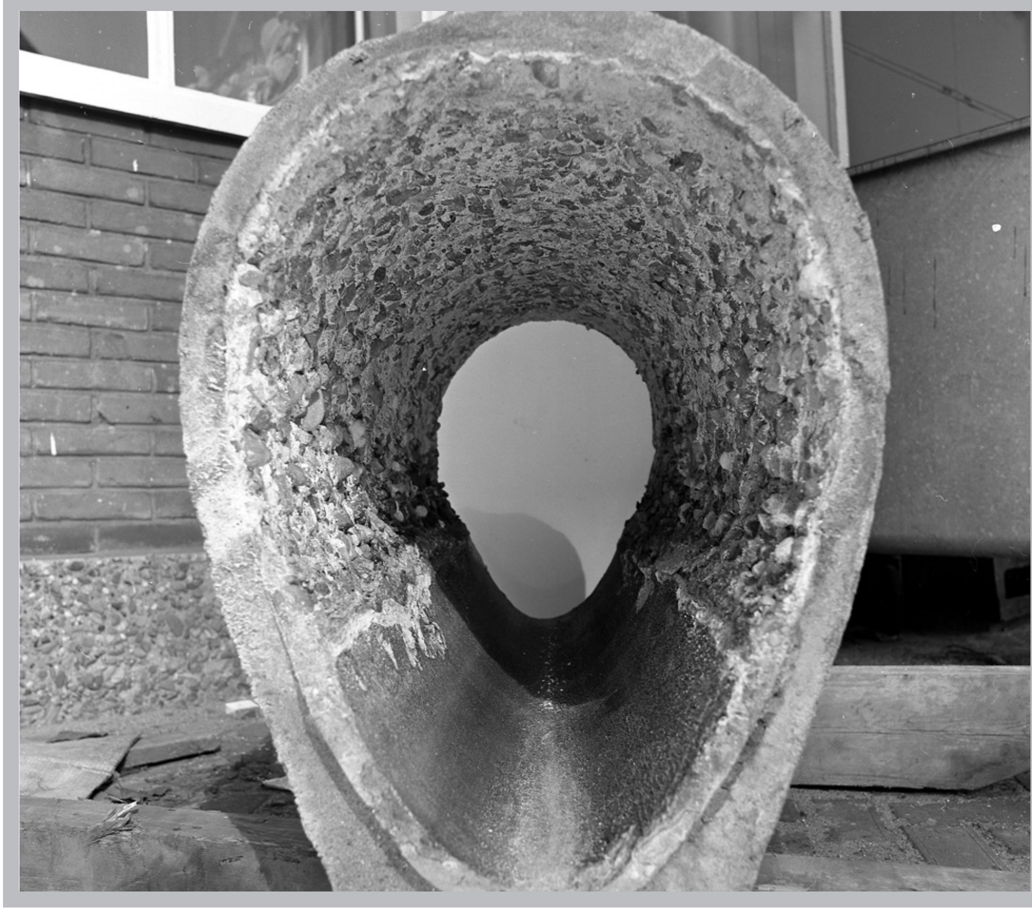
In a profiled joint the rubber ring is more enclosed than in the non-profiled joint. Again the rubber ring has an oval section. The initial groove ensures that less force is required to establish a connection than is the case with a non-profiled joint.

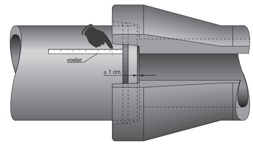
Figure 6.7 Profiled rolling joint principle



When assembling rolling joints, care must be taken to ensure that the pipe ends are pulled or pressed fully home and that the rubber sealing ring does not become dislodged. After laying each section of pipe, it is necessary to make sure that the rubber ring is seated sufficiently deep in the socket. The ring must not be located too near the edge of the socket. Bear in mind that the lower part of the joint is the most critical. With a profiled male pipe end there is less risk of the rubber sealing ring being incorrectly located (too close to the edge of the socket collar), but again the need to check after laying the pipe remains.
Most rubber sealing rings are made of Styrene Butadiene Rubber and are known as SBR rings. These seals are standardised and they are waterproof and capable of resisting bases and inorganic acids. Solvent-resistant NBR (Nitrile Butadiene Rubber) seals must be used if the sewage may contain hydrocarbons, petrol, oil, etc.
Concrete pipes are available in diameters of 250 mm to 2000 mm. They are manufactured using blast-furnace cement, which renders the pipes sufficiently resistant against the chemicals that normally occur in sewage. Caution is required in situations in which a sewer may be affected by biogenic sulphuric acid corrosion (due to H_2SO_4 being formed inside the sewer). In such cases the pipe can become corroded very quickly, and its strength drastically reduced.

Here are some examples of situations in which biogenic sulphuric acid corrosion can occur.
- At the discharge location of a sewage pressure pipeline, as a result of sulphides being formed in the pressure pipeline and turbulence caused by the discharge
- In sewer systems affected by uneven settling causing sewer sludge to collect and gases to be produced
- At discharge locations of factories discharging acidic process water, e.g. dairies, where the discharge of rinsing water containing milk causes lactic acid to be formed.





ASSIGNMENT
The illustrations in the text above show the principles of the sliding and rolling joint systems. In order to establish a connection between two sections, one of the two pipes has already been laid. The other pipe will have to be move to complete the joint. Which pipe has already been laid, and which pipe needs to be moved to complete the joint?
The pipe with the socket end has already been laid in the trench, and the male end with the rubber sealing ring is moved towards and into the open socket end. This is the same for both rolling and sliding joints.

Figure 6.8 Sewer pipe affected by biogenic sulphuric acid corrosion [Arnhem municipal archive / Province of Gelderland archive]

Plastic sewer pipes
Most plastic pipes for use in sewer systems are made of PVC, but sewer pipes can be made of other synthetic materials. This textbook will discuss only the PVC variant.

Two different types of PVC pipes are available:
- Standard PVC pipe
- Triple-layer PVC pipe, with the core containing recycled PVC.

The pipes are supplied lengths of 5 m and 10 m. The diameter of the pipes varies between 125 mm and 630 mm. The indicated diameters are the exterior diameters.

PVC pipes are available in different strengths and types. The property class of the pipes varies from SN 1 to SN 8. The number following the letters indicates the required circumferential stiffness, which is a measure of the force required to compress the pipe by 3% of the inner diameter with a certain velocity. The wall thickness depends on the property class being used, in other words, PVC sewer pipes have thicker walls as the property class increases.

Figure 6.9 PVC sewer pipes with socket joints

PVC pipes are available in the colours grey, brown-red, and green. The colours indicate the medium for which each pipe is intended:
- Grey is for rainwater
- Brown-red is for foul water or combined sewer systems

This colour coding scheme is not strictly applied within the Netherlands, and therefore situations may be encountered in which the two colours are reversed.
- Green is sometimes used for rainwater pipes.

The 125 mm and 160 mm diameter pipes are supplied with plain ends, i.e. without sockets. They are joined using a double-ended socket sleeve into which rubber seals have been factory-installed. The socket sleeve is pushed onto the end of one pipe, after which the other pipe is inserted into the remaining socket. Some pipes are available with extruded sockets at one end. (Extrusion is a manufacturing process in which hot plastic material is forced though a die under high pressure.) These sockets are factory-fitted with a rubber seal. The joint is created by sliding the spigot end of a new pipe into the socket end of the previously laid pipe. Before the joint can be made, the rubber seal must be coated with a special lubricant. The end sections of pipes that needed to be cut to size must be chamfered to make the joints easier to fit. Many types of fitting are available to pipes with each other and to produce custom solutions.

PVC pipes can handle the temperatures that normally occur in sewers. Tests have demonstrated that even temperatures as high as 70° C present no problems for these pipes. PVC pipes are highly resistant to the chemicals that can occur in wastewater, including the biogenic sulphuric acid (H_2SO_4) that is produced by processes inside the sewer.

Clayware sewer pipes
Clayware, or to give it its proper name, vitrified clayware, is a high-quality ceramic material produced by firing dried clay at high temperature (1200° C), changing the chemical and physical structure of the clay and turning it into a complete new material. The clay must be a rich in illite, and is mixed with grog (also known as chamotte, previously fired clay ground to powder).
The pipes can be supplied glazed or unglazed.

Clayware pipes are available with a moulded clayware socket at one end, or plain, without a socket. Socketed pipes are fitted with a polyurethane sleeve at the spigot end and a rubber seal inside the socket end. The spigot end of a new pipe is inserted into the socket end of a previously laid pipe. Pipes without pre-moulded clayware sockets are factory-fitted with a double-sided polypropylene (PP) socket sleeve at one end. The joint is then created by sliding another pipe into the other end of the socket sleeve. Both types of pipe produce a fully sealed and sufficiently flexible joint. Socketless pipes come in standard diameters of 100 mm up to 300 mm. Pipes with socket collars are supplied in diameters of 200 mm up to 800 mm. The length of the pipes varies from 2.00 m up to 2.50 m.

Figure 6.10 Ceramic pipes [Tauw]

As clayware is chemically inert, clayware pipes and fittings are not affected by chemicals, and will not be corroded as the result of biogenic sulphuric acid (H_2SO_4) produced by processes inside sewers. They are not affected by other acids either, with the exception of hydrogen fluoride (HF), a highly aggressive material used for etching glass. The joints are resistant to all types of domestic wastewater. The glazing does not have any additional protective purpose. Clayware sewers are long-lasting. If the sewage contains volatile hydrocarbons, a PVC or polyethene (PE, also known as polythene or polyethylene) pipe will slowly dissolve, whereas a ceramic pipe will not be affected. In addition to chemical stability, ceramic pipes offer high resistance to wear, which is why these pipes are very suitable for use in places where high wear rates are to be expected, e.g. in sewers laid at steep gradients.

6.1.2 Manholes

General
There are different reasons for including manholes in sewer systems. The most important ones are:
- To provide access to sewers
- To create junctions in sewers
- To create angular changes in addition to directional changes
- To change pipe materials and/or diameter
- To change the depth of the connected sewer pipes
- To connect (large) drains from connected properties to the sewer

The combination of manholes and the pipes between two manholes , known as a sewer section, ensures that wastewater can be collected and transported. Each sewer section travels in one direction only. In other words, sewers are laid out in straight lines between pairs of manholes. The maximum length of a section depends partly on the diameter of the sewer. For sewer diameters up to approximately 800 mm the section length is approximately 70 m, and for larger diameters the maximum length can increase up to 100 m. At manhole connections, the sewer level is always given in metres relative to the Standard Amsterdam Level (*Normaal Amsterdams Level, NAP*), measured from the invert (the inside bottom of the pipe).

The most commonly used manholes in sewer system are made of the same materials as used for the pipes. Pipes and manholes connected to each other can also be made of different materials. Below is a list of the materials used to manufacture manholes and the types of pipe that can be connected to each.
- Concrete: concrete pipes, PVC pipes and clayware pipes
- Polypropylene (PP) and polyethene (PE): PVC pipes and clayware pipes;
- Clayware (occasionally) of other materials: clayware pipes

In existing sewer systems we can find manholes made of all sorts of materials, including brickwork, concrete, and plastic. The two latter types are usually prefabricated.

Modifying prefabricated concrete manholes in situ cannot be recommended, because the quality of the product may be affected. The walls of sewer manholes can easily crack. Limited modifications such as drilling new holes are possible, however. The advantage of using brickwork manholes is that they can be made to measure for the location. Plastic manholes made of PP or PE can also be modified so a limited extent by drilling new holes and gluing in new connections.

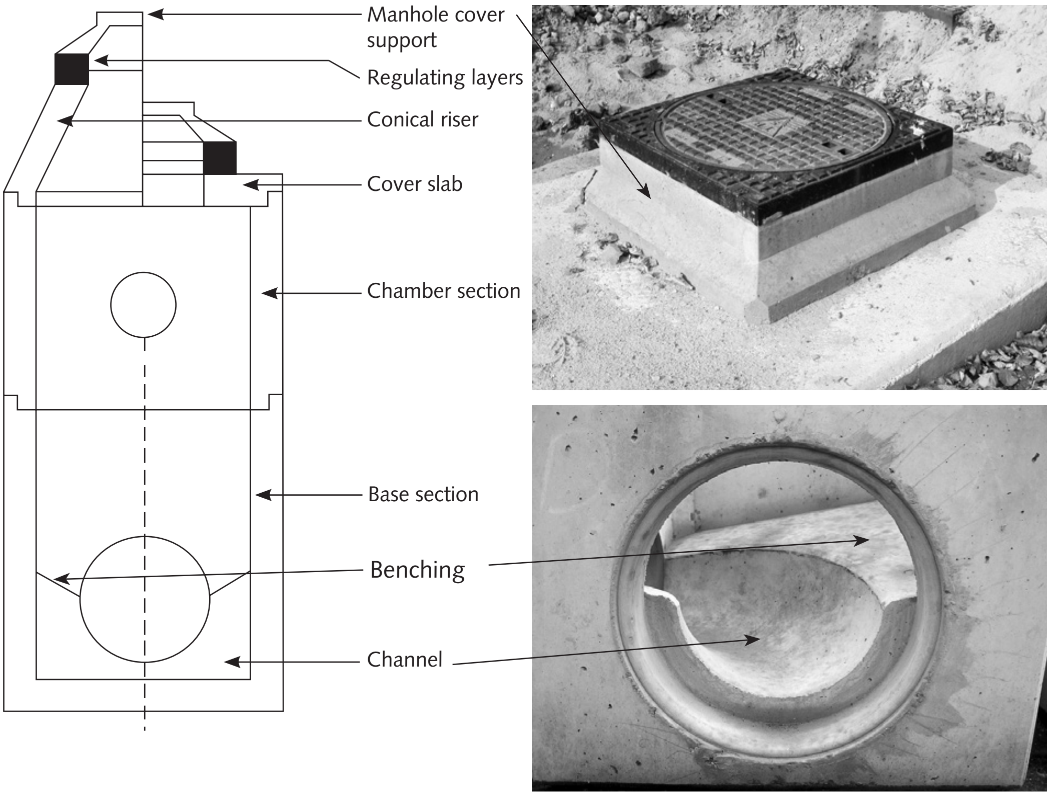
Figure 6.11 Brickwork manhole [De Hamer]

Concrete manholes

Concrete manholes come in may different sizes. Standard sizes are related to the diameter of the pipes that connect to the manhole. For smaller diameters, manholes with interior dimensions of 0.80 × 0.80 m and 1.00 × 1.00 m are often used. Circular manholes are also available.
Prefab concrete manholes always consist of several parts. Such manholes often include a base section, a chamber section, and a conical riser or cover slab. The joint between these components is sealed using mortar, a bituminous sealant, or by means of rubber sealing rings supplied with the manhole components. The upper edge of the chamber or riser is brought up to the desired level by means of regulating layers of brickwork or a succession of prefab concrete elements bedded in mortar. On top of these the cover slab is laid and fitted with the manhole cover assembly that allows access to the manhole.

Figure 6.12 Made-to-measure concrete manhole [De Hamer]

Figure 6.13 Prefab concrete manhole construction [VPB] and photo showing a manhole with a 90° bend channel [Photo: Hans Dijkstra, BvB/RIONED Foundation]



The base section of these manholes usually includes a channel created by the manufacturer. This channel at the bottom of the manhole guides the wastewater in the right direction. A channel must be laid out so as to minimise the resistance to the flow of wastewater inside the sewer system, i.e. following the natural hydraulic line of the water. The channel in a manhole must also be shaped to ensure that the sewage flow rate is not affected by the manhole, as this might cause sewage to build up in the manhole, ultimately blocking the discharge of wastewater through the sewer. The sloping part of the manhole between the channel and the manhole sides is called the benching.

The Dutch standard for prefab concrete manholes specifies a minimum benching slope of 15°. This is the gradient used in manholes for rainwater sewers. In order to prevent any sewage settling on the manhole benching of foul water sewers, the benching must be sloped at 45° or more. In some cases channels need to be created in situ. This is certainly the case in large prefab concrete manholes and in brickwork manholes.

In situations where concrete pipes connect to the manhole walls at right angles, the manufacturer will have included a circular hole with the same shape as the inside of a pip socket, allowing the concrete pipe to be simply connected to the manhole using a rubber sealing ring. If a PVC or clayware pipe is to be connected at right angles to the manhole, a casting box will be provided, or a rubber sleeve of rubber ring will have been cast into the manhole wall at the factory. Where non-standard connecting angles are required, short concrete socket sleeves must be cast into the manhole wall, or a masonry hole provided. To accommodate non -standard angles in PVC or clayware sewers, the wall of the manhole includes a thicker section set at the right angle which includes a concreted-in socket of the right type for the type of pipe to be connected. If a hole has been created by the factory, e.g. to brick in a pipe connection, a concrete socket or sleeve end of the shortest possible length should be included. The open space between the short length of pipe and the wall of the manhole should preferably be filled with concrete. If a full length of pipe (2.40 m) were to be connected with its end embedded in the concrete, there is a real risk of the pipe being fractured as the assembly settles. In cases where a PVC sewer or a clayware sewer needs to be connected through a hole in the manhole wall, a concreted-in socket can be used.

Figure 6.14 Use of a short adapter pipe at a manhole connection

In hilly areas the sewer system will need to include back drop manholes. These are manholes whose depth is used to bridge a local difference in level. The sewage drops inside the manhole well, as it were. Back drop manholes in sewer systems are to be avoided whenever possible, since they cause the contents of the manhole to be disturbed, which may lead to gases being formed which in turn may cause corrosion in the concrete sewer and the manhole. If the inclusion of a back drop manhole cannot be avoided, the drop should be kept as short as possible, to approximately 0.50 m. If possible the manhole bottom should also include a channel set at a gradient that bridges the difference in height between the two connected stretches of sewer as much as possible.

Plastic manholes
Plastic manholes made of polypropylene (PP) or polyethene (PE) exist that are suitable for connection to PVC sewer pipes. These manholes can be supplied in diameters of 800 mm (PP) and 1000 mm (PE), and come complete with channels and benching. Connections for sewers made of PVC or clayware can be fitted all around the manhole circumference, making changes in any direction easy to create. At the top the manhole has a rim onto which a concrete collar is fitted. Onto this collar, just like with a concrete manhole, adjusting constructions layers and a manhole cover assembly are installed. These manholes can also be supplied with a sand trap instead of a normal channel.

With plastic manholes a branch from the incoming sewer can ‘dive down’ at a 45° angle just before the manhole, while the original sewer continues straight on. Both pipes are then connected to the manhole, one above the other. The top connection leading into the original sewer is necessary in order to enable the upstream stretch of sewer to be cleaned and inspected. The drop problem in this case has been solved upstream of the manhole. With clayware pipes the same method can be used to overcome the difference in height in a back drop manhole. Below is an illustration of this layout.

Figure 6.15 Plastic back drop manhole layout [Wavin]

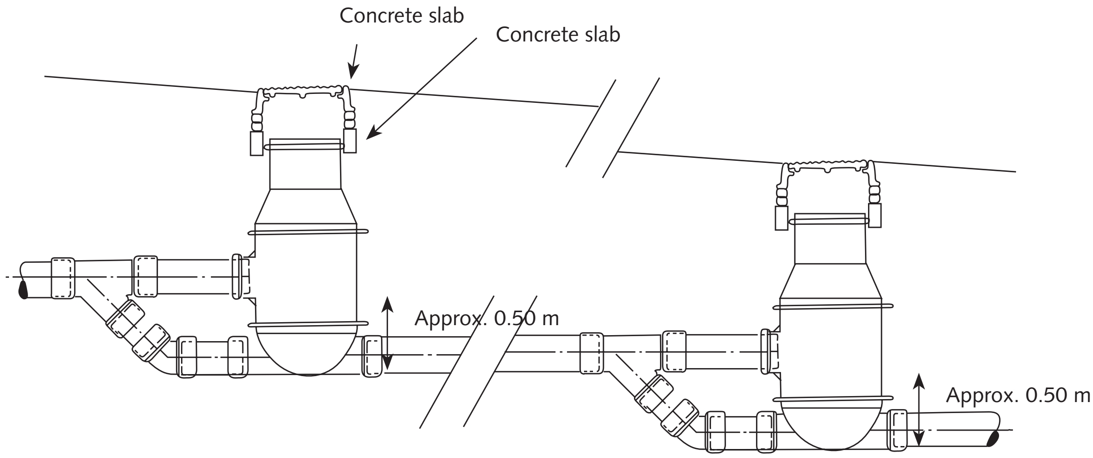


Figure 6.16 Plastic manhole with connections and plastic manhole with channel and connections

Clayware manholes

Clayware manholes do exist for use in combination with clayware pipes. These manholes consist of large-diameter circular clayware pipes. They are hardly ever used in the Netherlands.
There is a special kind of plastic manhole for use with clayware pipes. This type of manhole is manufactured from polyester resin mixed with a grit aggregate, and includes clayware butt ends cast into the material. The normal practice is to use plastic manholes or concrete manholes however, with clayware butt ends incorporated into the wall.

Figure 6.17 Clayware pipe connection in concrete manhole [De Hamer]

Manhole covers

The function of a manhole cover is to provide access to the manhole to allow inspection, cleaning, and maintenance to be carried out on the sewer system. Manhole covers consist of a cast iron access cover with a cast iron frame. Some covers include a grating to allow air into the sewer.
The function of the sewer may be included in an abbreviated form on the manhole rim, or as a full legend on the cover itself. If the function is applied to the manhole cover itself, the markings can easily become switched during maintenance. The application of the function on the manhole frame offers a major advantage in this respect. Two different types of manhole covers exist:

- Cover and frame made entirely of cast iron
- A cast iron cover combined with a narrow cast iron rim embedded in concrete

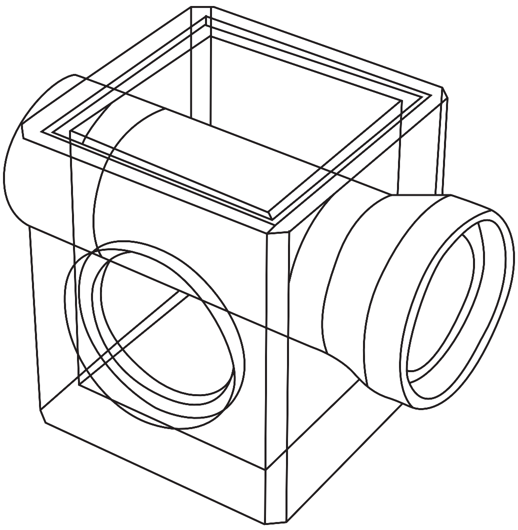
Figure 6.18 Examples of manhole cover slabs and manhole covers bearing the legend 'rainwater' [Betonplaza]

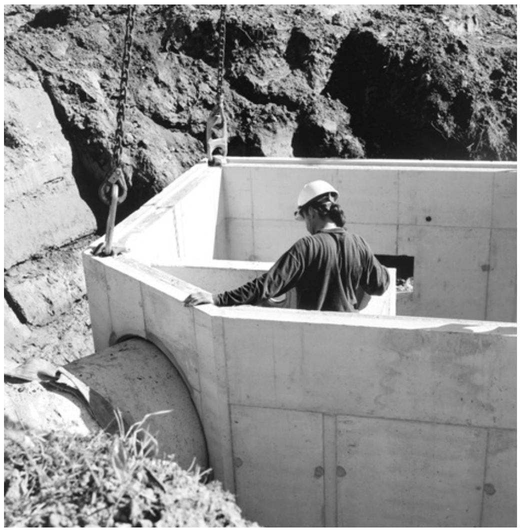
Special manholes
Very large manholes are assembled in situ using separate prefab concrete components for walls, floors, and cover slabs. The cover slab includes one or more holes on top of which the manhole cover or covers can be fitted. The channels are built into the manhole in situ.

In some cases a manhole does not only provide access to the sewer, but also serves a special function.

Here are some examples of such manholes:
- Manhole pipe: a combination of pipe and manhole, to be used if the sewer does not change direction, there is no junction of sewer sections, and no differences in height need to be overcome.
- Doghouse manhole: a manhole than can be built over and on top of an existing sewer section if a connection to an existing sewer is to be made. A concrete foundation slab is first laid below the existing sewer, onto which the manhole assembly is placed. The slots in the manhole walls that accommodate the existing pipes look like the access openings of a doghouse.

Figure 6.19 Example of a crossing manhole and a weir manhole [VPB].





ASSIGNMENT
The list above mentions a doghouse manhole. You are working on a foul water sewer. The description of the required assembly work is not complete. What is missing?
When laying the concrete foundation slab the existing sewer must be adequately supported to prevent uneven settling. The gaps in the manhole walls have to be sealed with concrete. In addition the top half of the sewer pipe (assuming a circular section) inside the manhole needs to be removed . The space between the sewer pipe and the manhole wall must be filled with concrete and finished with benching set at a 45° slope.

- Interconnecting manhole: a manhole in an improved separated sewer system in which a connection between a foul water sewer and a rainwater sewer is established. In order to prevent any backwash of foul water into the rainwater system the manhole includes a one-way valve;
- Crossing manhole: a manhole in which two pipes cross each other without being connected. A crossing manhole is used where pipes need to cross at more or less the same height.
- Internal overflow manhole: a manhole that includes an overflow sill to allow the sewage to overflow from one system into an adjacent system in order to make better use of its capacity.
- Weir manhole; the inclusion of an overflow sill and a restricted or controlled discharge capacity enables the upstream sewer to be used as a storage facility.

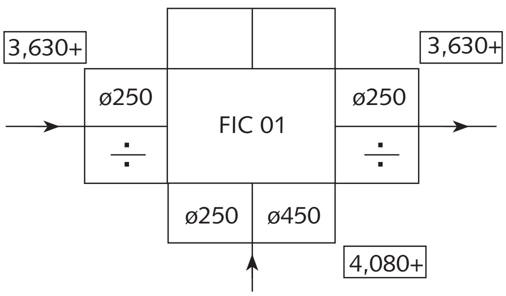
Manhole specification
A manhole specification is used to enable a manufacturer to make manholes that match the requirements and wishes of the customer in detail. The manufacturer prepares the manhole specification based on the specification drawings of the sewer system and the other relevant information he receives. Below is an example of a manhole specification for concrete manholes. Manhole specifications are also made for manholes in PVC and clayware sewers.

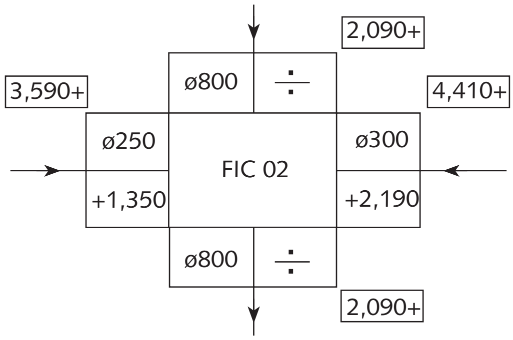
Figure 6.20 Example of a concrete manhole specification [VPB]

Client :

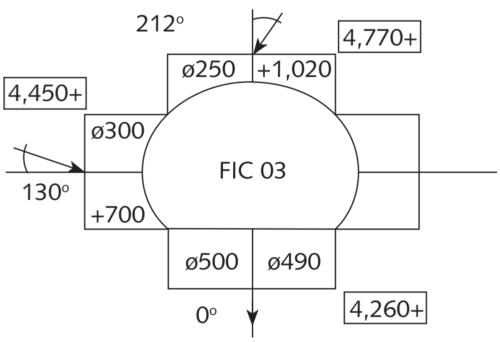
Work : **PAGENO.:** **3-4**

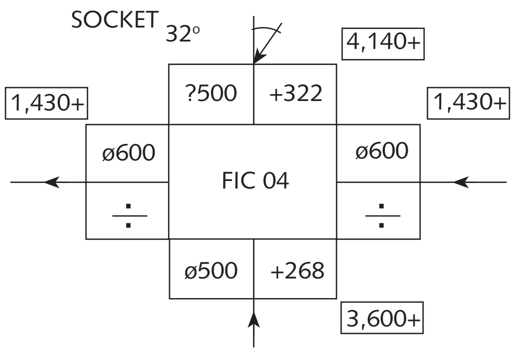
Manhole no.	01	02	03	04	Remarks
Manhole rim level	5,400+	5,460+	5,970+	6,010	Construction road level
Sewer invert level	3,630+	2,090+	4,260+	1,403+	
Pipe diameter	ø 250	ø 800	ø 500	ø 600	
Sand trap	---	---	600	---	
Outside manhole hight	1,980	3,760	2,330	4,820	Dimensions in mm





Manhole rim + adjusting layers	400		**Manhole rim + adjusting layers**	400
KLK 800 x 800	380		**K 1000 x 1000**	520
			R 1000 x 1000	800
			Ringbeam	---
OB 800 x 800	1,200		**OB 1000 x 1250**	2,040
Channel	1,980		**Channel**	3,760





Manhole rim + adjusting layers	400		**Manhole rim + adjusting layers**	400
SLAB ø 1200	150		**K 1000 x 1000**	520
			R 1000 x 1000 x 100	2000
OB ø 1000	1780		**OB 1000 x 1000 x 150**	1900
---	2330		**Channel**	4820

For each manhole, the specification must include:
- The code and manhole number, storm drain or foul water drain.
- The current or future road level over the manhole.
- The invert level of each of the connecting sewer pipes and their levels relative to the manhole bottom.
- The material and diameter of the sewer pipes.
- The walls to which the sewer pipes must be connected.
- Whether a sand trap or a flow channel is to be included.
- Whether the manhole is to be round or square.
- The angle at which the sewers must connect to the manhole wall (90° or otherwise).
- The total manhole height.
- The number and/or thickness of the regulating layers below the concrete or cast iron manhole cover frame.
- The make, type, and height of the manhole cover.

A sludge trap is a section of the manhole that sits below the imaginary line that connects the flow channels of the connected sewers. In storm drains this is called a sand trap.

Once the manhole specification has been prepared by the manufacturer, it is submitted to the customer for approval. The specification needs to be checked carefully to make sure the specification drawing and additional information have been correctly interpreted. The following matters need to be checked in particular:
- Any changes of direction of the sewers.
- The invert levels of the pipes.
- The pipe diameters, the type of pipe materials, and cut-outs.
- Whether a flow channel is required, and if so, its shape.
- The manhole dimensions and element heights.
- Reinforced concrete or not.
- Manhole legend.
- Manhole slab and regulating layers.

Once approval has been obtained for the manhole specification, the manufacturer will start to produce the manholes.

6.1.3 Gullies
The functions of gullies are:
- To collect the runoff from impervious surfaces.
- To allow solids carried along by the runoff to settle.
- To convey the runoff to the transport sewers.

Gullies are also made using different types of material. The bodies are available in either concrete or plastic. The gratings are usually made of cast iron, and can be roughly subdivided into two types, pavement gratings and road gratings. They come in many different models to accommodate practically any situation. The dimensions of gullies also vary widely. For security, gully covers can be supplied with locking systems that prevent them from being opened by unauthorised persons.

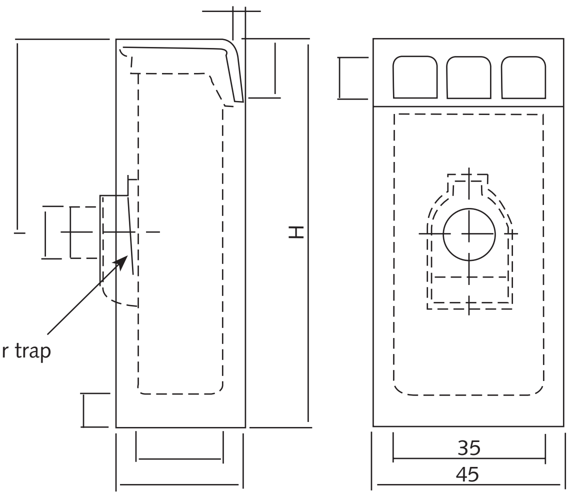


Figure 6.21 Various cast iron gratings and plastic gullies [Wavin]; concrete pavement gully and sectional view of a concrete pavement gully with a baffle acting as an odour trap

The distance between gullies serving a transport sewer is 20 to 25 metres. At corners they are usually place at the tangent points. The settling section of a gully should have a sediment capacity of at least 20 litres.

When gullies are used in a combined system, they must be fitted with an odour screen, usually in the form of a baffle plate in front of the pipe leading out of the gully. The edge of the baffle plate reaches down to a level approximately 0.05 m below the invert level of the outlet, creating a barrier that will prevent any odour from the sewer reaching the street.

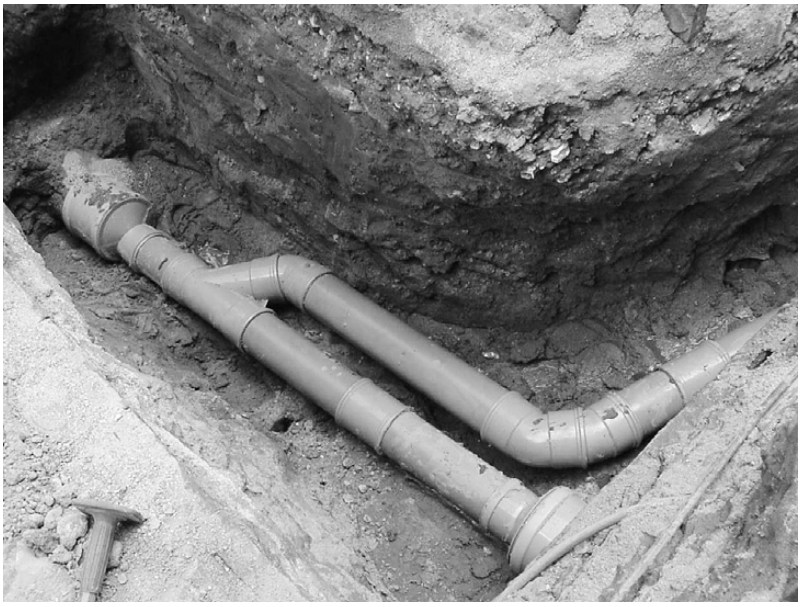
6.1.4 Connections to sewers

Drains connected to the sewer system can come from adjacent properties or from gullies and gutters in the road.

The following two categories can be distinguished:

- Domestic sewer connections that run from the property boundary down to the main sewer system, to infiltration systems, or sometimes to swales.
- Gully connections that lead from a gully down to the main sewer, infiltration system, or swale.

Figure 6.22 Domestic connections and a complicated connection



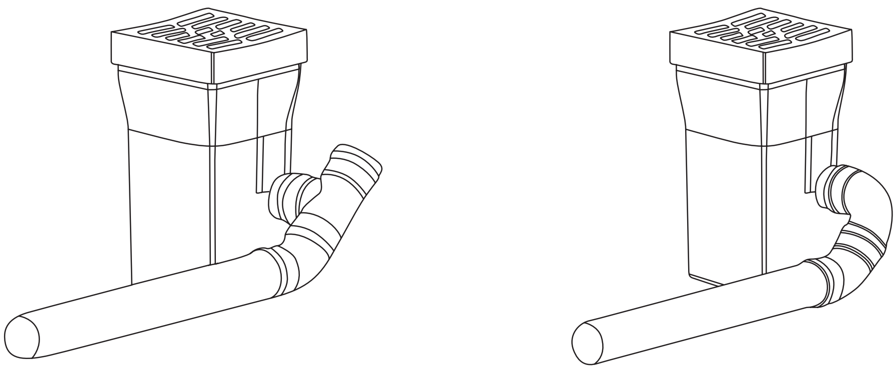
The connecting pipes are usually made of PVC or PP, and come in different colours. The following colour coding has been agreed to indicate different applications:

- Grey is for rainwater.
- Brown-red is for foul water or a combined drain.
- Green is for disconnected surfaces and leads to an infiltration sewer system or some other infiltration system.

The connecting pipes themselves and their connections to the new or existing sewer must be watertight. The ideal gradient of the pipes is between 1:100 and 1:200. The depth of domestic connections near the property boundary depends on the presence of cables and other pipes (e.g. below a pavement) and should be between 0.80 to 0.90 m. The cover of a gully outlet should be at least 0.70 m. The diameter of the connecting pipes must not be less than 125 mm.

Domestic connections must not be longer than approximately 20.00 m. A rodding eye/inspection cover must be included in an easily accessible location just within the property boundary.
Gullies must be connected to the outlet pipe so that any blockage can be easily cleared. The illustrations below show the best methods for this.

Figure 6.23 Methods for connecting gullies [Wavin]



To prevent blockage, any bends in the outlet pipes must be as gentle as possible. This is why only angled fittings of up to 45° are used, as shown in the pictures. The domestic and gully connections are connected to the top of the transport sewer at an angle 90° (i.e. vertically). The vertical section of the connecting pipes is called a riser. The transport sewer will have to include a facility for the riser to be connected to it, or it will have to be modified in situ.

The point at which the riser connects to the transport sewer is know as the (top) inlet. Each type of sewer material has its own way of connecting a riser to it. We need to distinguish between making the connections at the time the sewer is laid, or at a later date during the management phase.
We will now look at the inlet constructions of the various type of material in more detail.

Inlets on concrete sewers
For concrete sewers the inlets used during construction are different from those used later during the management phase:
- Construction phase: pipes with integral inlet.
- Management phase: concrete saddle (renovation block).

Where connecting pipes need to be connected during the construction phase, sewer pipes with integral inlets must be used. The inlets must be factory-installed. These inlets are located just behind the sewer pipe socket in order to weaken the sewer pipe as little as possible. The inlet in the concrete pipe can consist of an embedded PVC socket, or it can consist of a hole cut into the concrete into which a rubber sealing ring has been fitted. See the figures below for the different inlet constructions and a sketch showing the inlet detail near the socket end.

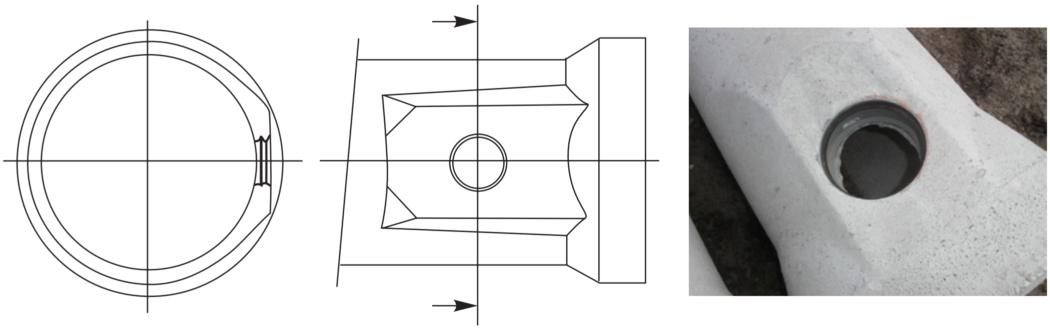


Figure 6.24 Sketch and photo [Betonplaza] of concrete pipe inlet construction

The connection to the concrete pipe must be made watertight. This can be done in three different ways. Referring to the diagrams below, from left to right:
1. An integral plastic socket embedded in the cast concrete.
2. A cut-out drilled into the pipe after the concrete has set, into which a plastic socket is pressed.
3. A cut-out drilled into the pipe after the concrete has set, into which a rubber sleeve is fitted.

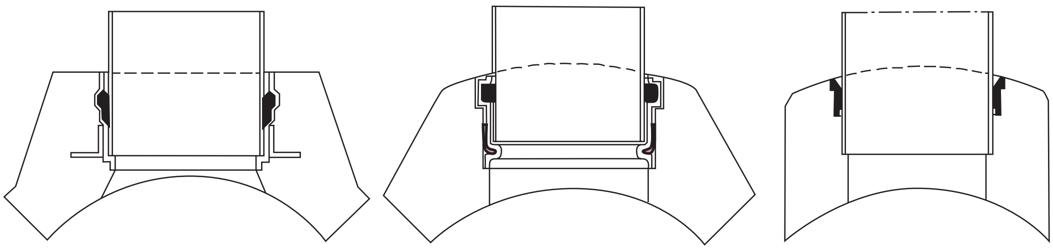
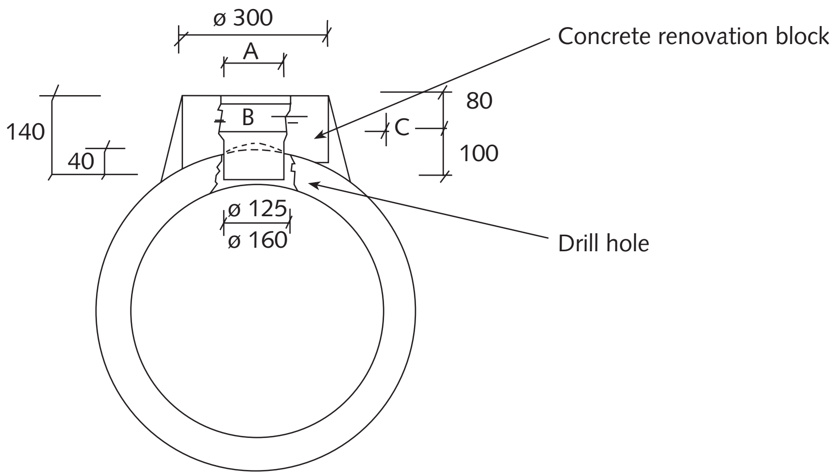


Figure 6.25 Different types of inlet [source: De Hamer]

The diameter of the inlets can be either 125 mm or 160 mm. If a larger diameter is required, 200 mm inlets are also available.

Figure 6.26 Renovation block for adding an inlet to an existing concrete pipe



In order to make a connection during the management phase, holes will have to be drilled into the sewer pipe. A concrete saddle with an embedded PVC pipe (renovation block) can then be fitted. Inlet dimensions are 125 and 160 mm. Between the concrete saddle and the pipe mortar or a bituminous sealant is applied to create a watertight connection. The PVC pipeline must be cut to length to ensure that the lower end sits approximately 0.015 m above the top inside of the sewer pipe.

Inlets on plastic (PVC) sewers
The inlets on PVC sewers are not installed at the factory. Round holes at the required locations on the sewer pipes will have to be drilled in situ. A watertight inlet connection can be made in a number of different ways. The two most commonly used types of inlet are:
- Screw type inlet.
- Lever type inlet.

Both types of inlet can be used either in the construction phase or in the management phase and they are available in diameters of 125 mm and 160 mm. The inlet can be fitted immediately after

Figure 6.27 Lever type inlet on PVC pipe [Wavin]

drilling a hole into the pipe. Both types of inlets are fitted with a rubber seal. In the screw type inlet a ring is screwed down to expand a rubber seal that wedges itself in the hole to provide a watertight connection. The lever type inlet is attached to the pipe by pressing down a pair of levers. With the levers down in the horizontal position the rubber seal is compressed against the hole drilled into the sewer pipe, again providing a watertight connection. Figure 6.27 shows an example of a lever type inlet with a built-in settling sleeve. A settling sleeve is a polypropene basket structure supporting the riser. As the riser is subjected to varying loads due to settling, the basket expands, allowing the riser to sink with the settling soil.

To avoid weakening the pipe too much, the distance between two inlets must be at least twice the pipe diameter, with a minimum of 0.50 m. The inlets must be arranged so as to allow the risers to be connected to the sewer at 90° angles.

Inlets on clayware sewers
In clayware sewer system, drains can be connected in either of two ways. We can use T-joints or pipes with factory-drilled round holes into which a plastic or ceramic inlet has been fitted. The inlets of the T-joints have a diameter of 100 – 200 mm. Inlets for drilled holes are available in 150 mm and 200 mm diameters.

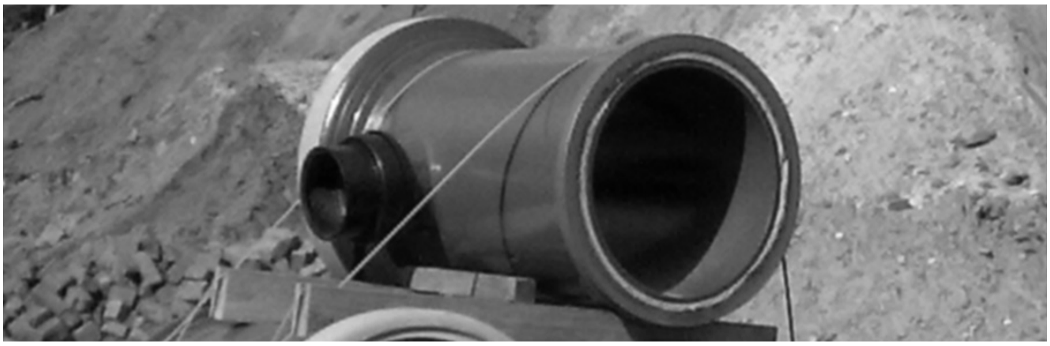


Figure 6.28 T-joint ceramic pipe for connecting a domestic drain or gully outlet

Clayware sewer pipes also offer ways of connecting new risers in existing situations (i.e. during the management phase). This can be done by drilling round holes in the pipe. A special clayware adapter providing a watertight seal is then fitted to the sewer pipe. Contractors should bear in mind that clayware is a ceramic material and that the firing process will have resulted in residual stresses in the pipe wall material.

6.1.5 Sewer pumping installations
A sewer pumping installation is a facility that pumps sewage. A sewer system includes different types of sewer pumping installations. According to their function we can distinguish:
1. Lift stations, which transport water from one sewer area to another.
2. Main pumping installations, which transport water from the end of the sewer system to the sewage treatment plant.
3. Overflow pumping installation, which transport overflow water to surface waters.

The most common sewer pumping installations found in sewer systems are numbers 1 and 2. Overflow pumping installations are not often found, and will not be discussed in this context.

Lift stations

In the flat parts of the Netherlands gravity transport without using sewer pumping installations would implicate that sewer systems at their lowest point would have to be laid many meters below ground level in order to ensure a sufficiently steep gradient. In most parts of the Netherlands, there is very little variation in ground levels within urban areas. This is why in the past different sewer areas were created. Each sewer area uses at least one sewer pumping installation , known as a lift station, to pump up sewage from the sewer system and transport it to the next pumping level. Even urban areas with large differences in ground level often use several pumping areas in order to be able to dispose of sewage from low-lying areas.

The shape and size of a pumping area is determined not only by the depth of the sewer system, but even more by the configuration of the area.

Main pumping installations

Ultimately the sewage has to be transported to the sewage treatment plant. In some cases this can be done purely by gravity, but usually a sewer pumping installation needs to be used. This main sewer pumping installation pumps up the sewage and sends it under pressure into pressure pipeline connected to the wastewater treatment plant.

Pumps

Sewer pumping installations commonly use centrifugal pumps, in which a rapidly spinning impeller induces a rotary motion in the water. The centrifugal force acting on the fluid causes the fluid to flow into a pump casing, where the kinetic energy of the fast-moving fluid is converted into pressure. Generally speaking, the pumping performance is determined by a combination of motor power, impeller type, and shape of the pump casing. The type of impeller used is determined by various factors:

- The required flow rate.
- The required pressure head.
- The nature of the pollutants in the wastewater.

Sewage pumps use the following types of impeller:

- Closed impellers
- Vortex impellers
- Shearing impellers
- Screw-centrifugal impellers

Figure 6.29 shows an example of a vertically mounted centrifugal pump with parts of its casing cut away to show the interior.

Figure 6.29 Example of a centrifugal pump with a closed impeller

Pump arrangement in sewer pumping installations
Sewer pumping installations fall into two main groups according to the way the pumps are arranged. Pumping installations built in the past and toady's larger pumping installations use a dry pump arrangement. Modern smaller sewer pumping installations use a wet pump arrangement. We will take a closer look at both types of sewer pumping installations below.

1. Sewer pumping installations with dry pumps
   This type of sewer pumping installation comprises at least a collection basin, known as a wet well, into which the sewer discharges its contents. The wet well is designed to make sure any solids are kept in suspension so they get transported to the pump intake together with the sewage. Sometimes the wet well contains a system of undulating gutters for this purpose. In addition to the wet well the pumping installation has a (dry) pump room and a control room. The pumps and motors are located in the dry room, but the intakes of the pumps are located in the wet well. This arrangement offers the advantage that motors and pumps are always accessible for maintenance purposes. The larger pumping installations usually include a superstructure over the pump room. This control room contains the electrical systems and the power switchboard. From the control room stairs provide access to the dry pump room. The control room also contains the hoist arrangement for the pumps. See figures 6.30 and 6.32.

Figure 6.30 Control room with pump hoist and hoist hatches

   The pumps can be lifted out of the pump room through holes in the control room floor that are normally covered by hatches. The construction costs of a dry pumping installation are higher than those of a wet pumping installation.

2. Sewer pumping installations with wet pumps
   In this type of sewer pumping installation there is no separate pump room, just a single well into which the sewer contents are discharged. The pumping system, which usually consists of one or more submersible pumps, is located inside the wet well, where each pump and motor is suspended underwater on a guide rail and chain. Using a permanent hoist system or a removable davit that can be placed in a swivel pot on the deck, the pumps can be lifted on their chains along the guide rail to be moved clear of the sewage for maintenance, inspection, of replacement. Since there is no control room, the electrical system etc. is housed in a separate (weatherproof) switch box.

Figure 6.31 Hoist system for wet pump arrangement

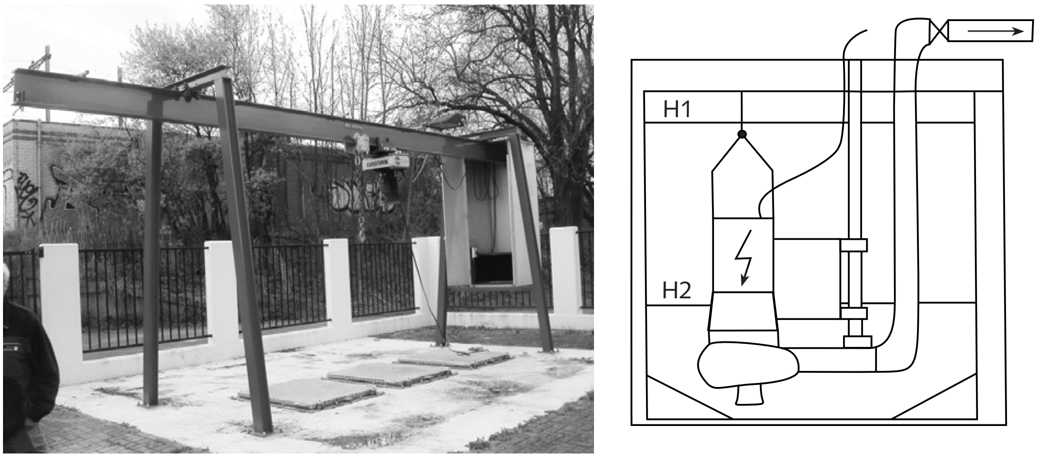


Figure 6.32 Superstructure of a sewer pumping installation and dry pump arrangement

Pumping schedule and sewer pumping installation switching levels
Reliability is essential for sewer pumping installations. This means that facilities must be provided to cope in the event of a pump failure. Therefore one or more backup pumps are installed. The required backup capacity is dictated in part by the type of pumps installed. In order to safeguard the proper operation of the backup pumps when required, they must also pump sewage from time to time. This can be done according to a certain predetermined schedule.

The switch-on level of the first (or single) foul water pump should be based on the pipe invert level. The switch-off level depends on the type of pump installed. The switch-on level of the second pump should be based on the water level in the incoming sewer at full foul water capacity. In a situation with foul water pumps and storm water pumps the following applies. The switch-on level of the foul water pumps is the same as that for foul water pumping installations. If there is a single storm water pump, its switch-on level should be that of 3 times the foul water capacity, or that of the excess pumping capacity. If there are multiple storm water pumps, the first storm water pump should come on a a level corresponding with half the excess pumping capacity, and the second storm water pump should come on at a level corresponding with the total excess pumping capacity. The switch-on level of the first storm water pump and the switch-off level of a second storm drain pump must be above the water-levels of any pumps previously switched on.

Examples of pump choices

- sewer pumping installations (foul water) in a separated system:
  - single main pump: single backup pump of the same capacity;
  - two or more main pumps: single backup pump of the same capacity as a single main pump.
- sewer pumping installations in a combined system:
  - two main pumps of identical capacities: a single backup pump of the same capacity as the main pump;
  - single foul water pump and single storm water pump: a single backup pump of the same capacity as the storm water pump, with speed control;
  - multiple foul water pumps and one or more storm water pumps: one backup pump with a capacity matching that of one of the foul water pumps and one backup pump with a capacity matching that of one of the storm water pumps.

Sewer pumping installation structures
In the larger sewer pumping installations the lower section is constructed using reinforced concrete. The concrete is usually cast in situ rather than prefabricated. The material used for the upper section depends on the exterior design of the building. In the larger sewer pumping installations with wet pump arrangements the reinforced concrete lower section can be either cast in situ or prefabricated. The smaller sewer pumping installations usually consist of a prefab concrete or plastic structure.

Pressure pipelines inside pumping installations
For safety reasons and to enable pumps to be removed for maintenance or replacement, both the intakes and the separate pressure pipes of the pumps must be closed off. For this purpose, shut-off valves are included in the pipelines. While the pumps are in operation, one-way valves prevent backwash problems.

Pressure pipelines outside pumping installations
Where the pressure pipeline emerges from the pumping installation, an expansion joint must be included with a facility to limit the maximum expansion.

The pressure pipeline is made of plastic or cast iron, depending on the required diameter. In curves the pipeline must be reinforced against bursting by using tension-resistant joints over a certain length. This length depends on the material selected for the pipeline, the operating pressure inside the pipeline, and the material used to backfill the pipe trench.

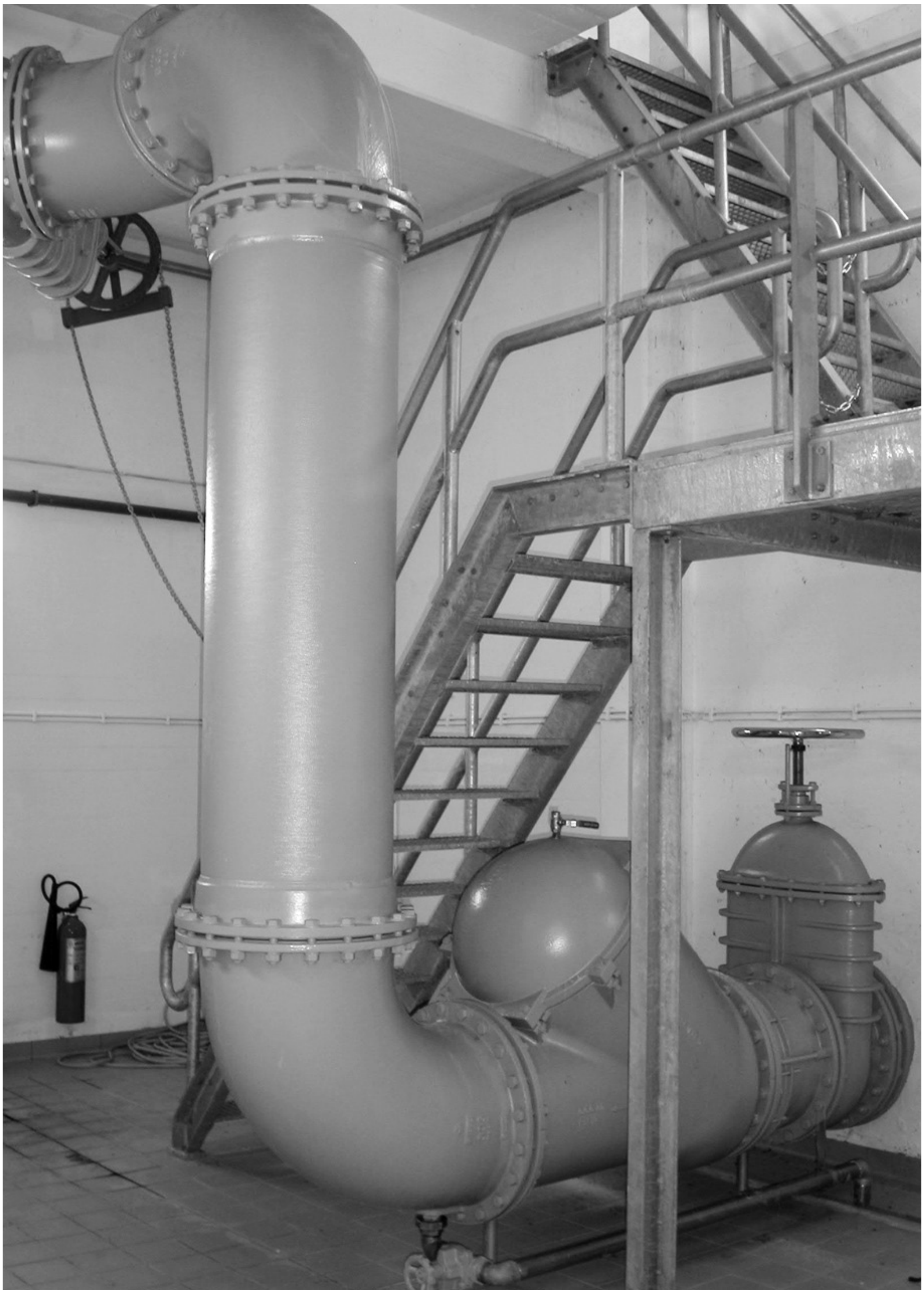
The property class of this pipeline material is not the same as for gravity sewers and must be based on the operating pressure. To allow a margin in the event of water shock in the pipeline, the operating pressure will need to be increased by a safety factor. In normal practice a safety factor of 1.5 is applied.
The pipeline must include venting facilities at the highest points.

Water hammer precautions
A sudden change of the flow rate in a wastewater pressure pipe can lead to water hammer, which is a sudden change in pressure. This can occur for example if a valve is suddenly closed, or if one or more pumps suddenly stop working as a result of mechanical failure or power loss. Water hammer can result in burst pressure pipes or damage to pumps. The severity of water hammer depends on the rate of the flow velocity change and the volume of wastewater inside the pressure pipeline.
In addition, pressure can build up more as the pipeline resists expansion. In larger systems a number

of safety mechanisms are used, including air chambers, venting valves, low-pressure risers, or buffer towers. See figure 6.33.

Connection to the power supply
The electricity powering pumping installations is supplied by a power company. The electrical system must be properly earthed, as must the reinforcing bars in the concrete.

Figure 6.33 Low-pressure riser to prevent water shock



Sewer pumping installation performance
To be able to assess whether a sewer pumping installation is operating as required, a number of measurements must be taken. Water levels in the wet well are recorded using level balances, pressure probes, or an ultrasound transmitter/receiver. Upwards of 100 m^3/h, and sometimes at lower capacities, flow rate measurements are taken.

Sewer pumping installation operational controls
In the most basic form the operational controls work like this: the pump switches on at the switch-on level, and switches off at the switch-off level. These days pumps are often controlled by means of a Programmable Logic Controller (PLC) of a control computer, with the automatic control sequences of pumps being programmed in the PLC of control computer using control software. The control sequences include the following status and fault signals:
- Water level too high
- Water level too low
- Power consumption too high
- Water in oil (leaking shaft seal)
- Power loss
- Control failure

Faults can be signalled by means of a red lamp on the control panel, using telephone text messaging, or by alerting a management system.

Telemetry
Pumping installations are often connected to a central location using a telemetry system. The telemetry system often forms part of a management system for multiple pumping installations. Telemetry is used for the following functions:
- Monitoring and adjusting the performance of pumping installations from a central location
- Gathering of measuring and operational data
- Transmission of measuring and operational data, including status alerts
- Recording of data at the central location.

Switch box
An outdoor switch box includes at least a compartment for the mains supply, the main fuses, the main switch, and the electricity meter. In addition the switch box must provide room for pump switching and control equipment, and optionally, telemetry equipment. This type of switch box is used in combination with a wet pump arrangement, since there is no superstructure. A switch box in a sewer pumping installation with dry pump arrangement and a superstructure will be larger to accommodate the more extensive electrical installation. Pump speeds are often controlled using frequency converters. These converters are also housed inside the switch box.

6.1.6 Overflows
The purpose of overflows is to divert to surface water any excess sewage that cannot be retained by the sewer system itself and that cannot be handled by the sewer pumping installation.

Overflows only come into operation if the water level inside the sewer system exceeds a sill level. The sill level is calculated on the basis of the sewer system storage capacity in combination with the risk and impact of overflow damage. This level is then fixed by means of an overflow sill built into a manhole. The overflow manhole is included in a sewer system and has a pipeline leading to the surface water. Inside the manhole, a brick partition is built up to the sill height to separate the sewer from the surface water. As soon as the water level in the sewer rises above the level of the sill, the water flows over the wall and is discharged into the surface water. To make sure the overflow works as designed, the use of a 'sharp' overflow sill is recommended. This can take the form of a stainless steel baffle with adjustable height. The advantage of this is that small corrections can easily be applied at a later time.

ASSIGNMENT
Find the best place to install a backwash blocking valve by making a sketch showing the various options.
The best place for a backwash blocking valve is above the normal surface water level, either in the discharge pipeline or directly above the overflow sill. This allows us to check the operation of the valve and carry out maintenance if necessary.

As mentioned in section 2.1 there are two types of sewer system in which the overflows must be included in the sewer system in order to be able to handle the large inflow of water in the event of heavy rainfall. These sewer systems are:
- Combined / improved combined sewer system
- Improved separated sewer system.

The overflow sill is preferably designed to be at a level above the highest known or calculated surface water level. If the surface water level can exceed the level of the overflow sill, a means of preventing backwash must be incorporated. This can be effected by including a one-way valve in the discharge pipeline or on the overflow itself. The one-way valve will be closed in the following conditions:
- The water level in the sewer system is below the overflow sill
- The difference between the sewage level and the surface water level is less than the head required to open the valve. The head needs to overcome the resistance of the hinge and the weight of the valve shutter.

Figure 6.34 shows an example of an overflow manhole.

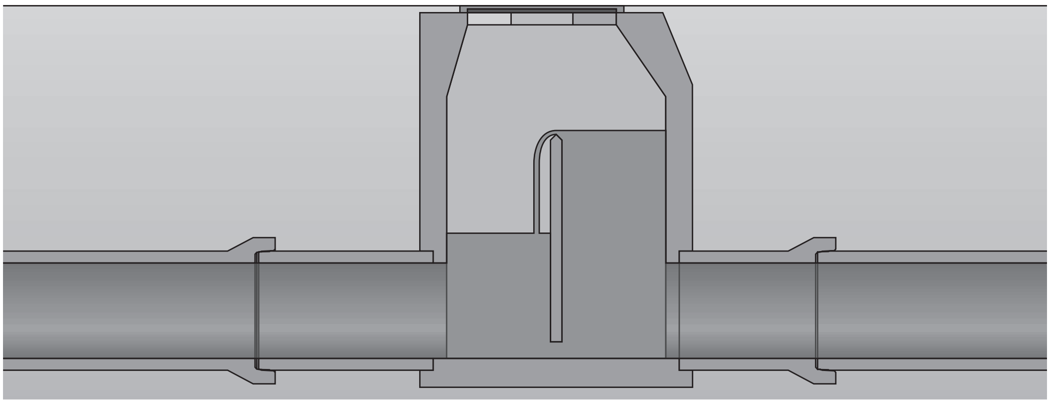


Figure 6.34 Overflow manhole [VPB] with an open overflow connected to a discharge pipe

6.1.7 Storage and storage/settling facilities

The main purpose of these facilities is to ensure that the sewer system complies with the basic effort requirement. In other words, the emission of wastewater into surface water is limited by adding storage capacity to sewer systems and including storage/settling facilities. These peripheral facilities are added after any existing or new overflow sills and serve to reduce the emission of waste from a sewer system. Such peripheral facilities are usually added to existing combined sewer systems. In certain cases they have also been used in separated systems.

A second purpose is to minimise the number of flooding incidents that could lead to problems such as water entering premises or critical locations in the sewer system, with the risk of damage and subsequent claims for compensation.

The function of storage facilities is to add storage capacity to sewer systems. Storage facilities include:

- Storage capacity outside the sewer system
- Storage capacity inside the sewer system
- Green storage capacity/flexible storage capacity

The function of storage/settling facilities is to provide temporary storage for wastewater and to allow solids to settle. Any sewage exceeding the storage capacity then overflows into surface water. When the rain stops, the sewage and the sludge is returned from the storage facility to the sewer system and then transported to the sewer pumping installation. Storage/settling facilities include:

- Storage/settling basin
- Storage/settling sewer

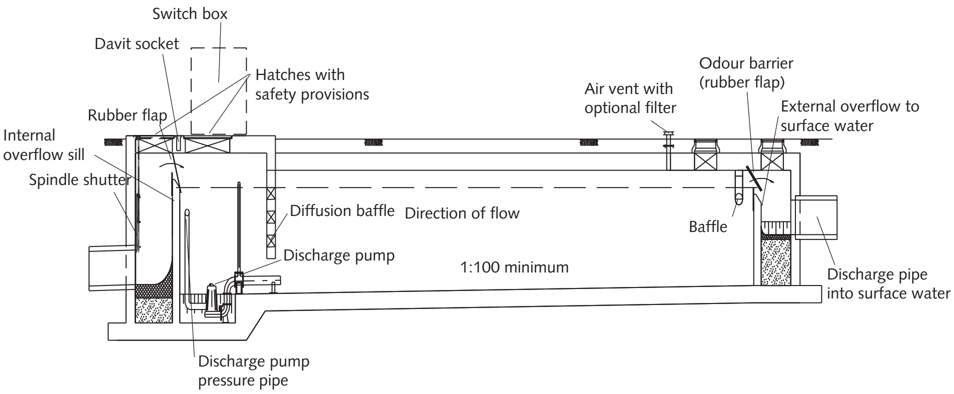
We will take a quick look at each of these facilities below.

Storage outside the sewer system
The purpose of extra storage capacity outside the sewer system is to prevent flooding situations. This is done by slowing down the flow of rain into the sewer system. In other words, any precipitation is temporarily stored in basins in the area where it falls before it is allowed to flow into the sewer system. This reduces the peak load on the sewer system, hopefully keeping it within the available capacity offered by the sewer system. A major prerequisite is that the storage capacity must be available afresh within a reasonably short period. This means that the storage capacity must be emptied by flowing into the sewer system within 20 hours.

Storage capacity within the sewer system
Areas built on a slope offer the option of including an additional storage capacity upstream in the existing transport sewer system in combination with one or more weirs. The storage capacity itself requires a less hilly location, where the sewers will also be laid at flatter gradients. The weirs may be fitted with remotely operated shutters to control the water flow into the lower parts of the sewer system. This allows the peak discharges to be buffered so the maximum discharge can be limited to the actual flow capacity available in the lower area.

Storage/settling basin
A storage/settling basin is a special form of reservoir in a sewer system. The difference between a storage basin and a storage/settling basin lies in the fact that a storage/settling basin is designed to enable solid waste to be separated (by sedimentation and/or flotation) so they can be removed from the basin.

Figure 6.35 Storage/settling basin



Storage/settling basin with diffusion baffle under construction [De Hamer]

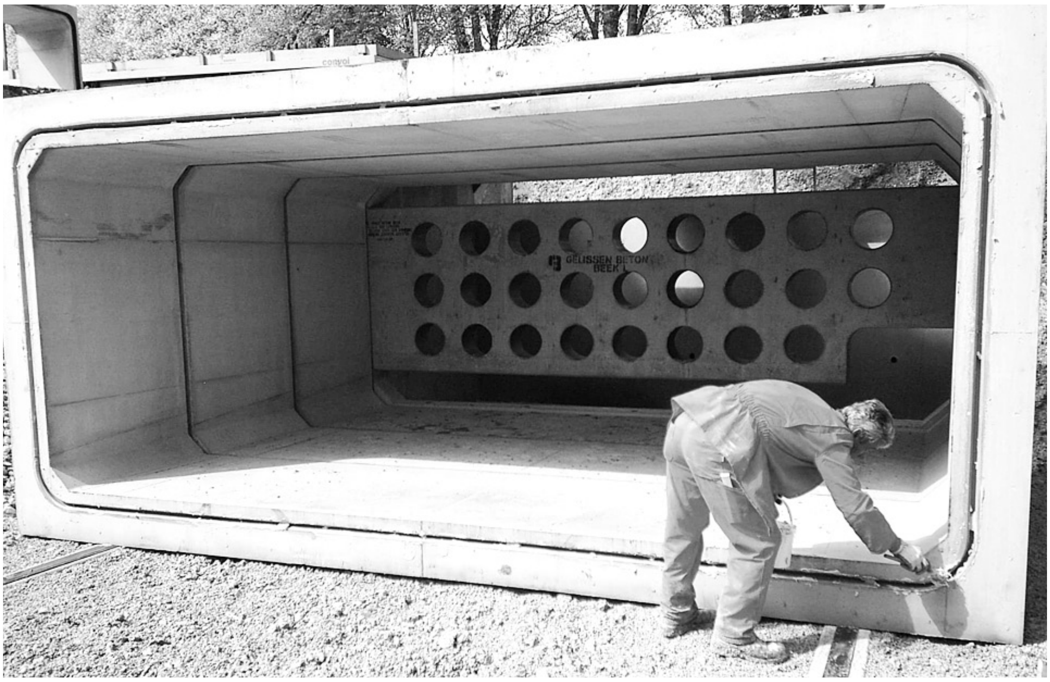


Figure 6.35 includes a sketch showing the principle of a rectangular storage/settling basin. The internal overflow sill ensures that light rainfall will not enter the basin.

Baffles are included to prevent any floating material being released onto the surface water. The floating material can range from large timber objects to the scum that is created as light solids float up from the bottom of the storage/settling basin.

Each time after the basin fills, the remaining sludge needs to be removed. As much of the sludge as possible will be returned to the sewer system in such a way that the sludge will reach the sewage treatment plant. To ensure that all the sludge is returned to the sewer system after the rain stops and after most of the sewer system has been pumped empty one or more flushing and/or jet pumps are used. In most cases the basin contents need to be pumped back into the sewer because there is an insufficient drop to enable the basin to empty into the sewer system by gravity.

If there is a sufficient drop towards the sewer system, the basin can also be flushed using a flushing chamber filled with sewage. To clean the basin, valves in one or more inlet connections near the bottom of the basin can be automatically opened, and the resulting water surge carry any sludge back into the sewer system.

Storage/settling sewers
Storage/settling sewers are in fact nothing but ordinary sewers designed to allow sludge to settle and to be cleaned after an overflow occurs. The advantage of a storage/settling sewers is that they take up less space. Often an existing sewer system can be used, offering a relatively cheap alternative to a storage/settling basin.

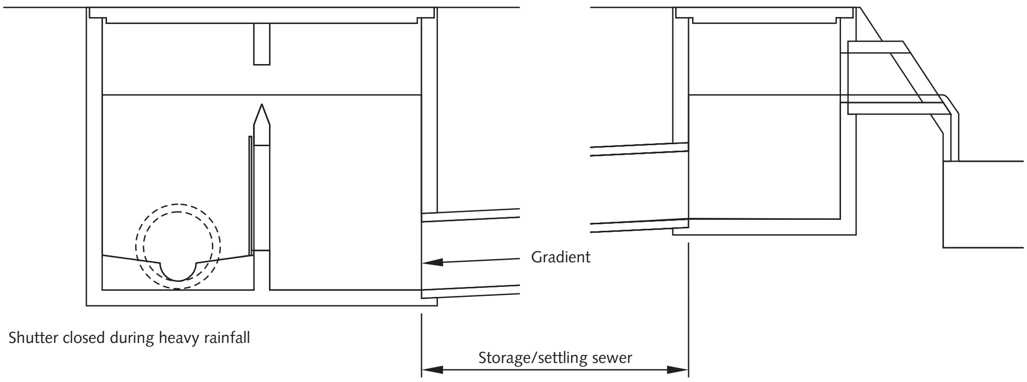


Figure 6.36 Storage/settling sewer [VPB]

Research has shown that the a well-designed storage/settling sewer can minimise the discharge of waste just as well as a storage/settling basin.

Green storage capacity/flexible storage capacity
A green storage capacity is included as a second stage behind an existing storage facility to further increase the storage capacity of the sewer system. It is used mainly in cases in which the surface water demands a very high level of protection.

The most common form of this type of storage facility is a basin planted with grass. Although these basins can also be covered with tarmac or concrete, they tend to take up lots of space, making them difficult to fit into the landscape.

The flexible storage capacity offers an alternative to the green storage capacity. It is a closed membrane structure that can be either accommodated in a dug-out on land, or under water (in a pond). In the event of extreme precipitation, the 'bag' fills with sewage.

6.1.8 Infiltration sewers
The sewer pipes discussed in the previous sections all share a closed structure designed to prevent any sewage escaping from the pipe. Storm water sewers are increasingly designed or modified to be disconnected from the wastewater system. In addition there is an increasing desire to retain rainwater permanently, i.e. store it in the soil.

The traditional closed-structure pipes are unsuitable for transferring the collected rainwater from the pipe into the soil, so other pipes were developed that do have the ability to let through water. We call these infiltration pipes or IT pipes.
Infiltration pipes can be made of the following materials:
- Concrete
- Plastic: polypropene (PP)

Concrete IT pipes
The concrete pipes are available in two variants. One is a pipe with an open wall structure, allowing the water collecting inside the IT pipe to escape in any direction. The other type of pipe is a pipe with a closed wall structure in which 16 circular holes with a diameter of 18 mm have been made. These pipes are wrapped in geotextile.

The pipes feature socketed joints with a rubber ring seal as used in closed pipes. The open wall structure pipe must be connected to a manhole using a closed pipe. The pipes come with the same type of inlets as closed pipes. These pipes are supplied in diameters of 300 – 800 mm. The length of the pipes is 2.40 m and the diameter of the inlets on the pipes is 125 or 160 mm.

Plastic IT pipes
Plastic IT pipes are made of polypropylene. Polypropylene pipes consist of a smooth internal pipe with ribs on the outside. These ribs contain the slots through which the water can escape into the soil. As these ribs fill with water, they add to the storage capacity.

The pipes are available in diameters ranging from 200 mm to 600 mm, and 800 mm. The pipes are supplied with a factory-extruded socket.
The manholes supplied for these pipes are the same as those for PVC sewer pipes, and the pipes can be connected to the manholes in the same way as PVC sewer pipes.

Figure 6.37 Plastic IT sewer [Wavin]

Inlets are also made in the same way as for PVC sewer pipes, and lever-type inlet are also available. The colour of the pipes is green. For connections to concrete IT pipes and to PP pipes green PVC pipes in diameters of 125 mm and 160 mm are used. The joints between the pipes use sockets fitted with a rubber sleeve.

6.2 Designing sewer systems
Chapter 5 looked at the hydraulic design of sewer systems. In section 6.1 of this chapter the various components of a sewer system were presented. In this section 6.2 you will learn how to design a sewer system.
Section 6.2.1 looks at what is required in order to make a well-considered choice of sewer system. The following section discusses the route of the sewer and the location of the sewer within the sectional view of a road. Finally, section 6.2.3 looks at the factors that affect the foundation and structural integrity of sewer pipes, providing insight into the forces acting on sewer pipes and their effects on the materials and the supporting structure.

6.2.1 Sewer system design

Once the choice of what type of sewer system to use has been made, the result needs to be converted into a design. This gives rise to a number of questions:

- What will be the physical appearance of the choice of sewer system?
- Where should any sewer pumping installation be located?
- Where will any overflow discharge points be located?
- Where is the right type of surface water available for discharges?

Sewer system choice

A choice has been made to separate the discharge of foul water and storm water. The separated discharge of rainwater can follow several options, some of which are listed here:

- Separate foul water and rainwater sewers constructed as an improved separated sewer system
- Separate foul water and rainwater sewers, with the rain water sewer discharging into surface water, optionally after passing through a treatment plant
- Separate foul water and rainwater sewers, with the latter discharging into the soil where possible, and partly into surface water
- A separate foul water sewer and an entirely surface-located discharge of rainwater, e.g. using gutters giving onto surface water, with or without infiltration.

A choice from the above will depend on the local conditions, and is not a choice between essentially different solutions, but a choice of what the system will look like. The list above provides an outline, and there are many more options that can result in a well-designed sewer system.

You should start by wondering whether all the options for discharging rainwater have been exhaustively catalogued. You will soon discover that this is not the case. A good guide to fill in the gaps could be the Interactive Decision Support System for the sustainable handling of rainwater (*Interactief Beslissing Ondersteunend Systeem voor duurzaam omgaan met regenwater, IBOS – Regenwater*: www.ibos-regenwater.nl). This site, which can also be reached through the site of the RIONED Foundation, www.riool.net, offers tailor-made information about policy, legislation, and effects of sewer disconnection, and about the disconnection process itself.

In order to arrive at a well-balanced choice of sewer system, a number of issues will have to be looked into.

If an improved separated sewer system is selected, rainwater will have to be discharged into the foul water sewer. The capacity of this sewer must be sufficient to cope with this. The water board sets requirements regarding the quality of the rainwater to be discharged into surface water, so the rainwater may need to be treated first. If so, a choice of treatment method will have to be made. If you opt for infiltration, you will have to find out about the long-term groundwater table readings for a period of at least one year, preferably several years, noting the mean highest groundwater table and the mean lowest groundwater table. You will also need to carry out surveys to find out what the layers of the subsoil are, and what the horizontal permeability of the soil is. Then there is the question of how to introduce the rainwater into the soil. You could use infiltration sewers, but perhaps you could use swales instead. If you opt for a surface-located discharge system, you will have to check the road gradients to make sure the system will work. You will have to compare the initial costs of the different designs as well as the long-term maintenance and running costs. All in all, you will need to carry out a lot of work before you can make a well-considered decision.

Location of sewer pumping installations
The ideal location of a sewer pumping installation in a newly developed or redeveloped area is in the centre of the area, in other words in the centre of a circle. You should choose the location of a sewer pumping installation so that the lengths of the sewer connections to the outlying areas all have roughly the same length. Bear in mind that pipelines may have to follow roundabout routes, so you cannot simply use a straight line from the furthest point to the sewer pumping installation. The maximum depth of a sewer pumping installation usually is 3 to 4 m.
Always take a critical look at the given conditions, including the soil structure, to see which depth is practical for the sewer pumping installation. You do not want to break through an impervious soil layer and cause a seepage problem, for example. Therefore it may be necessary not to lay the sewers very deep, so you may need more than one sewer pumping installation. Other reasons why more than one sewer pumping installation may be required are:
- Sewers are too deep
- Impractical gradients
- Intersections with waterways

The cost involved in the construction of a sewer pumping installation is high, so all options must be carefully considered.

Location of overflows and rainwater discharge points
The location of an overflow in an improved separated sewer system must be near a sufficiently large expanse of surface water. The storage capacity and discharge capacity of the surface water must be capable of accommodating the overflowing water without causing environmental or health problems. The same applies to the discharges of rainwater from a separated sewer system. This is the quantitative aspect. There is also a qualitative aspect, taking into consideration the function allocated to the surface water. Another point to consider is that the surface water must not be stagnant.

6.2.2 Routing and cross section
Before the hydraulic design can be made, the sewer routes must be determined. This is done on the basis of a zoning scheme or urban design. During this phase you are already mindful of the proposed roads, streets, and paths, which fix the main structure of the sewer system.

There is more to designing a system than just the technical aspects and the urban layout. In a newly developed area the various development phases need to be taken into account, as they may affect the sewerage design. You will preferably do so before the hydraulic design is made.

Once is has become clear what your choice of sewer system will look like, the sewer system can be designed in detail, addressing such issues as:
1. The final routing based on the urban planning, connecting all the projected properties to the sewer system.
2. The site levels: are they free to choose, or have they been fixed?
3. The materials to be used.
4. Sewers gradients and invert levels, solutions for intersections with other pipes, ducts, cables, and surface water, and minimum cover requirements.
5. Determining the location of the sewer system in the cross section taking into account existing or proposed cable and pipeline zones and trees to be planted.

Routing
There will usually be an urban design or layout plan. Using this and the known preconditions, the sewer routes can be drawn in. In addition to the urban plan, the sewer routing should also take into account the plan's proposed roads, streets, and paths. The available road widths, distance from buildings, cables and pipes, or the projected cable and pipe zone, and the type of foundation of the buildings all affect the routing of sewers that are deep underground or have a large diameter. If the plan would require very long connecting pipes (over 20 m) to the transport sewer, an extra sewer route will have to be planned.

Sewer routes normally follow the layout of public highways and paths. Make sure your routing will enable every property to be connected to the sewer system.

Site levels
The question is whether the levels of the site will remain as they are. If they are to change, what will the new site level be? You may need to make special arrangements for existing buildings on sites where the site level cannot be changed.

Choice of material
Choose the right material. There is a great deal of difference between concrete with a relatively thick wall, and PVC or clayware with a relatively small thickness. The type of cross section also makes a difference. If you decide to use an ovoid pipe or a pipe with a flat base, this will affect the depth of the system and the solutions at intersections.

In addition to the above aspects, your choice of material is affected by the local soil structure, the loads to which the pipes will be subjected, the medium to be transported, etc.

Sewer gradients and invert levels
Start with the minimum cover at the outer ends and for initial sections. Generally speaking this minimum cover will be 1.20 m to 1.40 m. This depth is required because the property connecting pipes have a cover of at least 0.90 m in the public zone to allow cables and pipes to cross. The use of settling sleeves in the risers will help to establish additional cover depth.

Start with initial gradients for the foul water sewers of 1:200 – 1:300, gradually changing to 1:400 – 1:500. For large areas you can go as low as 1:700 – 1:1000. Rainwater sewers in an improved separated sewer system have gradients varying from 1:750 to 1:1000.

The diameter of the foul water sewers varies between 200 mm and 250 mm. Make sure your gradients can overcome the sludge shear stress. The diameters of the rainwater sewers follow from the hydraulic calculations. The minimum diameter is 250 mm.

Make sure the outsides of crossing sewers are at least 0.10 m to 0.15 m apart. Be aware of any stretches of water the sewer may have to cross.

ASSIGNMENT
A sewer system is to be constructed under an existing road within area designated for future development in the zoning scheme. The levels of the road have been measured at 50.00 m intervals. At the first measuring point the foul water sewer lies at 8.80 m above NAP. Due to the road gradient the upstream section of the sewer system could only be laid with a minimum cover of 1.20 m. The local sewer gradient is 1:500 and the diameter of the concrete sewer is 250 mm. The site levels 50.00 m intervals are 10,00, 9.70, 9.50, 9.40, 9.50, 9.70, 9.90, 9.90, and 9.60 m above NAP. You can assume the maximum manhole distances.

Draw a longitudinal diagram and indicate how the sewer runs. Indicate the maximum manhole distance.

The first two sewer sections must be laid deeper in order to achieve the minimum cover of 1.20 m. The levels of the remaining sections are not affected. The last manhole at a distance of 375 m from the start is at an invert level of 7.30 m above NAP. The maximum manhole distance is 75 m.

Figure 6.38 Sewer trench with two sewers [De Hamer]

Sewer system location in the cross section
Draw cross sections of the roads and draw in the proposed and existing cables and pipes. Include any planned and existing trees. The normal distances from the sewer centre line are:

- Cables and pipes (utilities): 1 – 1.5 m;
- Trees: 1.5 – 4 m depending on the type of tree and the groundwater table.

Based on the required distances, choose the position of the sewer system within the cross section. Sewers should preferably be located in the centre of the road, or below other hard surfaces such as paths. In most cases the foul water sewer and the rainwater sewer are laid alongside each other. The minimum distance between the two depends on the choice of material and the dimensions of the sewers.

6.2.3 Foundation and structural integrity of sewer pipes
When designing sewer systems it is important to use pipes that are strong enough and to ensure that they are laid on a proper foundation. Underground sewer pipes are subjected to large loads. To gain insight into the interaction between the load on the most common types of pipe for sewer systems (concrete, clayware, and pvc) and the surrounding soil, you will have to study the theoretical background. Another factor that should not be ignored is the way the soil settles. In a situation with a soft subsoil offering little support settling differences can eventually cause the sewer system to no longer comply with the design gradient. The settling differences can even cause the sewer system gradient to become inverted so the sewer can no longer drain properly, leaving stagnant contents behind. In these situations you will have to choose between a natural foundation or piles, or the intermediate form of including a load-spreading layer under the sewer pipe.

Stress calculations for sewer pipes are best left to specialists, and a full calculation of a sewer pipe is outside the scope of this publication. However, after reading this section you will have gained some insight into the forces that act on sewer pipes.

Calculation method in the Netherlands
The calculation method for the structural integrity of sewer pipes is described in:
CUR report 122: 'Underground pipes. Calculation of non-reinforced and reinforced concrete pipes' (*Buizen in de grond. Berekeningen van ongewapende en gewapende betonnen buizen*)

The (German) *Arbeitsblatt* ATV-DVWK A127 'Guideline for static calculations of drainage channels and pipes' (*Richtlinie für die statische Berechnung von Entwässerungskanälen und -leitungen*).

CUR 122 deals with concrete pipes only and is limited in that pipes with non-circular sections, such as ovoid pipes or pipes with a flat base, cannot be calculated. The CUR report 122 builds on the ATV method, elaborating, expanding, and defining it for the Dutch situation.

Plastic sewer pipes are often calculated using the German *Arbeitsblatt* A127 of the German DWA (*Abwassertechnische Verein, ATV*). The CUR and ATV methods both use Leonhardt's theory to describe the interaction between the forces acting on a pipe and the resulting stresses around its circumference.

Soil Mechanics
Most of the soil in the Netherlands consists of loose and fine material. You know this from your soil mechanics course, which also looked at the background information, so these need not be discussed in the present context.

The simplified calculation according to the CUR report 122 and the ATV-DVWK A127 use the following subdivision into three groups:
Group 1: **Soil types with little or no cohesion**, known as non-cohesive soil types. They have low compressibility and high permeability.
Group 2: **Cohesive mixed soil types.** The behaviour of these lies somewhere between the types of groups 1 and 3.
Group 3: **Cohesive soil types.** These are often compressible and have low permeability.

For soil types or other materials that do not fit into either of the above groups, including **organic soil** types like peat, the values must be calculated for each individual case. Organic soil types are highly compressible with low permeability and low cohesion. Like the soil types of group 3 the behaviour of these soil types varies widely over time.

All the soil types listed above have specific behaviours when subjected to loads. Predicting the behaviour of a pipe in the soil with any accuracy requires good insight into the current properties of the specific soil type into which the is to be laid. For this purpose you can have cone penetration tests carried out, augmented if necessary by deep soil sampling. You know from soil mechanics that these can provide a pretty accurate picture of the various subsoil layers and of the strength and stiffness of the various layers.

Loads
Underground sewer pipes are subjected to various loads, the most important of which are:
1. Vertical loads caused by the weight of the soil above the pipe
2. Traffic loads
3. The pipe's own weight
4. The weight of the pipe's contents

Once you know these loads, you can calculate the stresses involved and the required strength of the pipeline. Of course, the type of loads to which the pipe is subjected may vary from case to case. You should also distinguish between the construction phase and the utilisation phase, since the loads involved can vary widely between the two.

Soil load
The weight of the soil that sits above a pipe acts as a load on the pipe. In a simple calculation you can simply use the weight of the soil column directly above the pipe. The size of this load depends on the outside diameter of the pipe, the soil cover, and the weight of the soil. A simple calculation is included here.

Given:
Sewer pipe material: concrete
Inside diameter of the pipe: 600 mm with a wall thickness of 79 mm
Soil type: clay with a volume weight of 17 kN/m³
Soil cover above the pipe: 2.50 m

Question: What is the soil load in this case?

Solution:
Outside diameter: 600 mm + 2 × 79 mm = 758 mm = 0.758 m
Soil pressure: 17 kN/m³ × 2.50 m = 42.5 kN/m²
Soil load: 42.5 kN/m² × 0.758 m = 32.2 kN/m¹
In formula form this becomes: $q_v g = \gamma * H * D_u$

in which:
γ = Volume weight of the soil above the pipe, in kN/m³
H = Soil cover, in m
D_u = Outside diameter of the pipe

The amount of soil load on pipes in reality depends on differences in stiffness between the pipe and the surrounding soil and between different sections of soil. For the differences in stiffness between the pipe and the soil we use the system stiffness ratio (V_{RB}), which indicates to what extent the circumferential stiffness of the pipe and the stiffness of the surrounding soil contribute to the support of the pipe (the system stiffness ratio is obtained by dividing the pipe stiffness by the soil stiffness). In other words, it shows us whether we are looking at a flexible or rigid pipe. The following formula applies:

$$V_{RB} = EI / r^4 * C_H$$

in which:
V_{RB} = System stiffness ratio
EI = Bending stiffness of the pipe wall
r = Mean radius of the pipe
C_H = Horizontal modulus of stiffness of the soil alongside the pipe

The boundary between flexible and rigid has been defined as $V_{RB} = 0.1$.

A pipe with a low (circumferential) stiffness (= EI / r³) relative to the stiffness of the soil (= r * C_H) receives much of its support from the soil pressing against the sides of the pipe. In order to achieve any horizontal supporting pressure on a flexible pipe some deformation of the pipe will be required, making it slightly oval in section as the side walls of the pipe move outwards against the soil, building up horizontal soil pressure. As the horizontal soil pressure builds up, it counteracts the deformation and reduces the moment in the pipe structure. The maximum vertical load the pipe can bear depends in part on the horizontal stiffness of the soil next to the pipe. Incompressible soil (compacted sand) will be able to supply the required supporting pressure. In compressible soil such as clay or peat the increasing pressure will start a consolidation process that will cause the resulting supporting pressure to almost disappear as time passes. The extent of the required deformation depends on the load acting on the pipe and the stiffness of the soil next to the pipe. If a pipe is stiff compared with the surrounding soil, little supporting pressure will be created, and the pipe will carry most of the superimposed load by itself.
Figure 6.39 below shows the system stiffness ratio for different pipe materials.

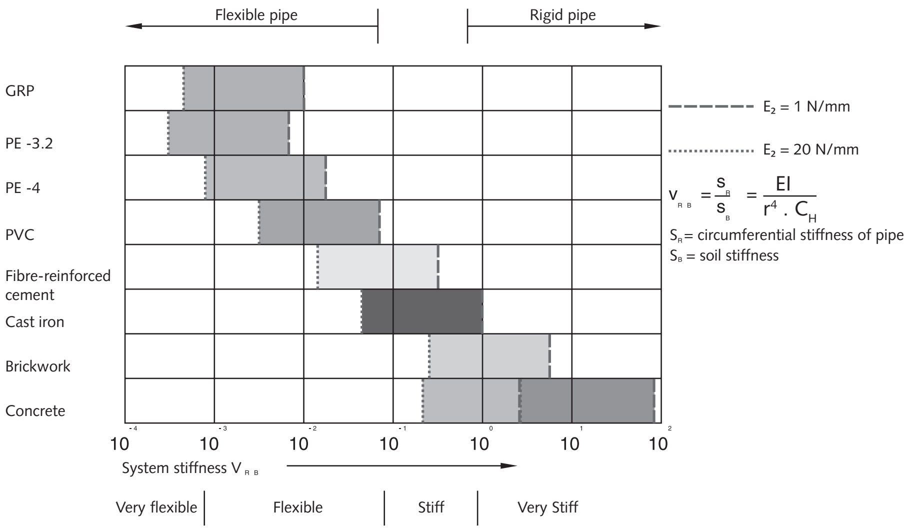


Figure 6.39 System stiffness ratio

The diagram above shows that plastic pipes are flexible and that concrete pipes are rigid.
In situations in which the soil and the pipe are equally stiff, the deformations of the pipe and the adjacent soil are equal, and as a result there will be no difference in movement between the soil directly above the pipe and the soil next to it. If the movement of the pipe is equal to that of the soil next to it, no shear stresses will occur along the column of soil above the pipe. In this case the top load on the pipe is equal to the weight of the soil sitting above the pipe. We call this the neutral soil load. With a neutral soil load (practically no additional horizontal soil pressure against the pipe) the following formula applies:
$\lambda_{vg} * \chi = 1$

in which:
λ_{vg} = Concentration factor of the soil load
χ = Reduction coefficient of the soil load due to the hopper effect

Note:
The approximation formula for λ in a fully rigid pipe is given on page 26 of volume 5 of 'Sewer Systems Technology, The structural calculation of concrete pipes and manholes' (*Rioleringstechniek, De constructieve berekening van betonnen buizen en putten*). This publication can be read on-line at www.betonleeft.nl under '*kenniscentrum*' (Dutch only).

Taking into account the concentration factor of the soil λ, the flexibility of the pipe, and the reduction coefficient χ due to the hopper effect, the formula for calculating the soil load is:

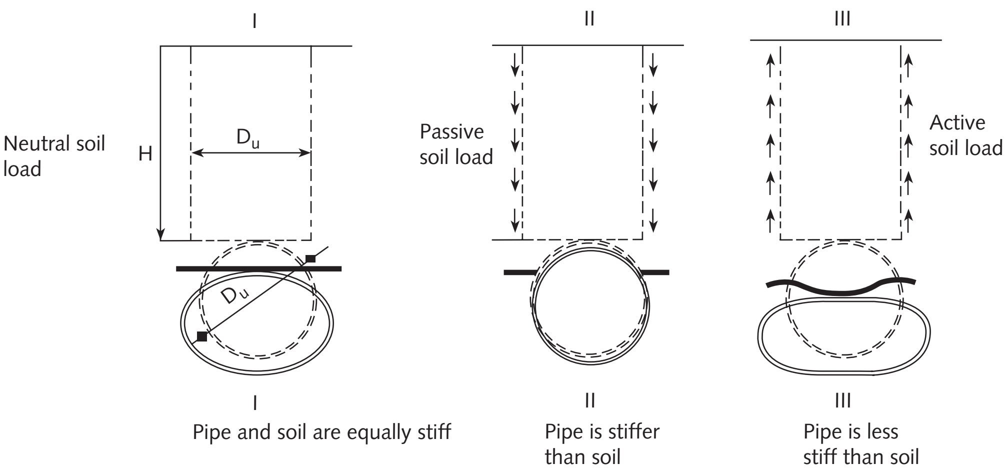
$q_{vg} = \lambda_{vg} * \chi * \gamma * H * D_u$

in which:
λ_{vg} = Concentration factor of the soil load (load factor), which depends on V_{RB}.
χ = Reduction coefficient of the soil load due to trench wall friction (hopper effect)
γ = Volume weight of the soil above the pipe, in kN/m³
H = Soil cover, in m
D_u = Outside diameter of the pipe

Generally speaking λ_{vg} varies between 1.0 for fully rigid pipes to 0.1 – 0.5 for flexible pipes.

The situation in which the soil and the pipe are equally stiff is shown in situation I in the figure below. As the figure shows, there are three different situations as far as the hopper effect is concerned:
1 Situation I: the pipe and the soil are equally stiff
2 Situation II: the pipe is stiffer than the soil; mostly concrete
3 Situation III: the pipe is less stiff than the soil; mostly plastic

Figure 6.40 Soil load on flexible and rigid pipes



If a sewer pipe is supported by piles, the soil usually offers little support, while the piles structure is rigid. Any soil next to it will settle considerably. Therefore a pile-supported pipe results in a high passive soil pressure.

Situation II shows a passive soil load. The stiffness of the pipe exceeds that of the adjacent soil. Under the same load, the soil next to the pipe is compressed more than the pipe. The column of soil above the pipe is subjected to a downward shear stress, causing the adjacent soil to cling to the pipe, increasing the load on the pipe to more than just the weight of the soil directly above the pipe. The passive soil pressure situation occurs with concrete pipes laid in compressible clay of peat.
The following formula applies: $\lambda_{vg} * \chi \geq 1$

ASSIGNMENT
If a sewer pipe is supported by piles, which type of soil load applies? Include a sketch.

In situation III the pipe is more flexible than the surrounding soil, which is known as an active soil load. The pipe will deform as a result of which an upward shear stress acts on the column of soil above the pipe, so the soil column is partly supported by the soil next to it. This reduces the load on the pipe. Active soil pressures occur mainly with flexible (plastic) pipes laid in relative incompressible sandy soil. The following formula applies: $\lambda_{vg} * \chi \leq 1$

Traffic load
The effect of the traffic load on an underground pipe depends on the axle loads of the vehicles and on the soil cover. Since it is impractical to calculate the load on the pipe for each and every type of vehicle, standard load systems (notional vehicles) have been introduced.
These load systems are shown in NEN 6788, The design of steel bridges – Basic requirements and simple calculation rules (*Het ontwerpen van stalen bruggen – Basiseisen en eenvoudige rekenregels*) – VOSB 1995 and in NEN 6706, Technical principles for building structures – TGB 1990 – Traffic loads on bridges (*Technische grondslagen voor bouwconstructies – TGB 1990 – Verkeersbelastingen op bruggen*). Both standards are expected to be replaced by a new European standard in the spring of 2010.

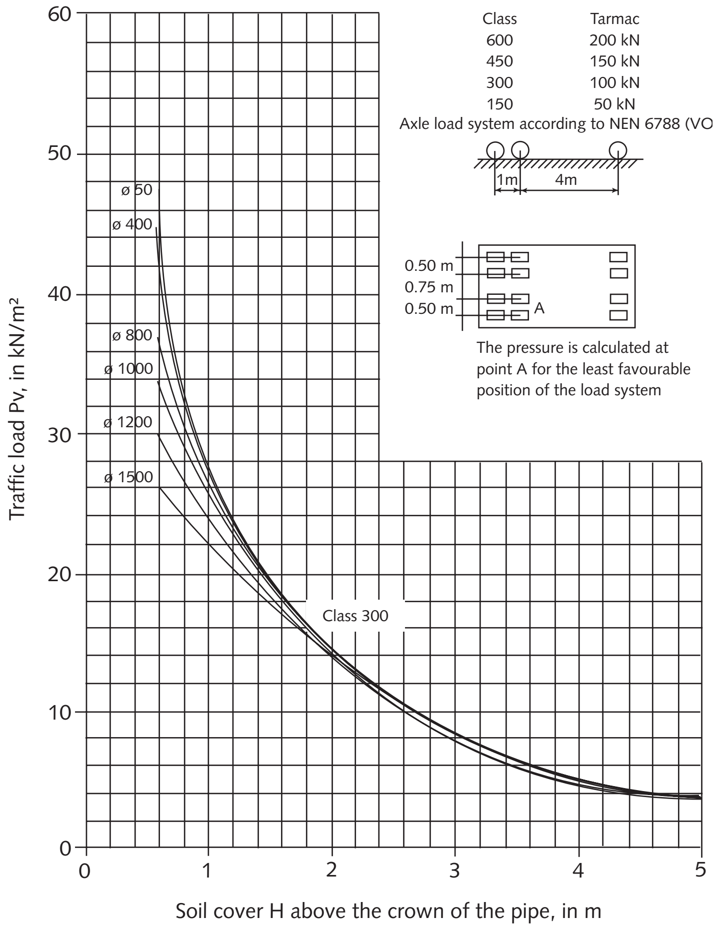


Figure 6.41 Traffic load for traffic class 300, without impact coefficient [NEN 3650]

The pressure is calculated at point A for the least favourable position of the load system
The figures in the standard represent the weight of the typical vehicle (in KN). The weight of the vehicle is transferred through the wheels to the road surface and subsequently transferred to the soil. During this transfer the load is spread, so that the stresses in the soil due to the traffic load decrease with depth. The traffic load can be determined using the Boussinesq formula. For a traffic load right over the pipe this is:

$$P_v = \frac{2 * P}{\pi * H^2} \text{ kN/m}^2$$

in which:
P_v = Vertical stress on pipe due to the traffic load, in kN/m²
P = Traffic load, in kN
H = Soil cover, in m

Taking into account the impact coefficient and the traffic concentration the traffic load on the pipe becomes:

$q_{vv} = S * \lambda_{vv} * P_v$

in which:
q_{vv} = Load on the pipe, in kN/m²
S = Impact coefficient
λ_{vv} = Concentration factor of the traffic load
P_v = Traffic load, in kN/m²

Impact coefficients are given in table 6.1.

Table 6.1 Impact coefficient according to DIN 4033

Class	S
600	1.2
450	1.3
300	1.4
150	1.5

Pipe weight
The weight of the pipe itself is a load that induces stresses in the pipe wall. Just like the weight of the pipe contents the pipe weight has little effect, and should be included in calculations only for large diameters in concrete.

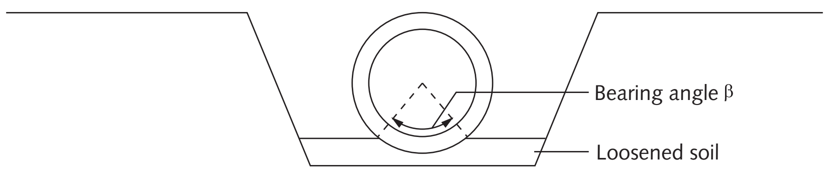
Pipe contents
The contents of a pipe also act as a load on the pipe wall . The load will be low for small diameters, but in pipes with large diameters it can increase considerably.

Foundation pressures
The bearing width is the width of the contact surface between two objects or materials. To simplify calculations, for pipes embedded in soil this width is expressed as an angle, known as the bearing angle β (= 2 α). The bearing angle is determined to a great extent by the soil types below and directly adjacent to the laid pipe, the method of pipe-laying, and the way in which the soil under the pipe is compacted.

Table 6.2 Practical bearing angle values

	β = 2 α
Rigid pipes	30º – 45º
Flexible pipes	60º – 120º

Figure 6.42 Bearing angle principle [VPB]



For pipes laid in the soil the calculations are based on the assumption that the pipe is loaded over its full width, with a load angle of 180°.

The bearing angle and the load angle have a considerable effect on the moments that are induced in the pipe wall . For a small bearing angle an identical top load will result in a much larger deformation of the pipe and consequently, larger bending moments in the pipe wall. Since the bearing angle affects the load-bearing capacity of the pipe so much, it is important that the bearing angle value used in the calculation is actually achieved.

Sewer foundation methods
To make the right choice of foundation, soil mechanical data based on cone penetration tests and soil samples will be required. You know that insight into the soil condition and an analysis of the settling prognosis will determine the choice of the foundation type (see also NPR 3218, chapter 7). They also affect the calculation method to be used for the pipes.

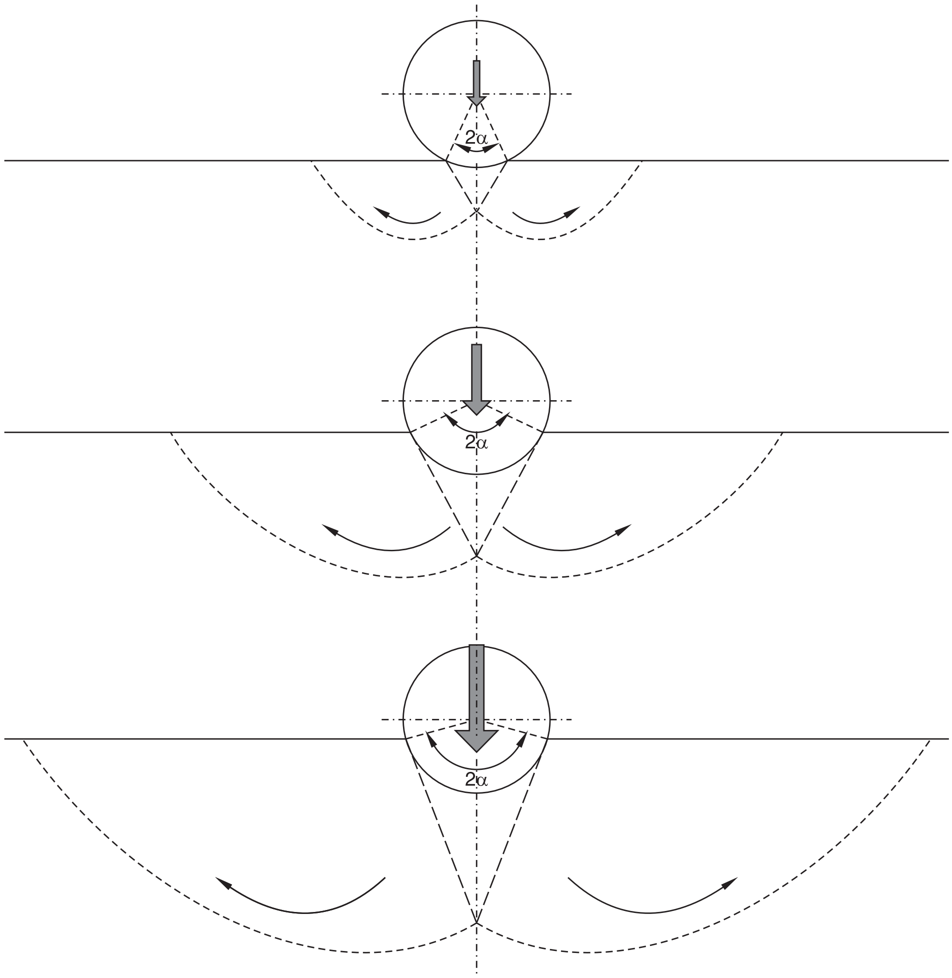
The calculation of the pipe considers the circumference of the pipe. In a pile-supported sewer the loads are transferred along the length of the pipe. The top load acts on the entire length, whereas the pipeline may only be supported in certain places, depending on the choice of pipeline foundation.

Other discontinuities in a pipeline can also result in stresses that need to be included in a calculation. They include manholes, differences in soil type, and different construction methods.
Roughly speaking there are three different types of foundation:
1 Natural
2 Plastic foam
3 Piles

Choosing between piles and natural foundation
In a natural foundation almost the entire load is transferred directly, i.e. the pipe gets pushed some way into the soil. How much the pipe gets pushed into the soil depends on the stiffness of the soil under the pipe, expressed as the bedding constant. A high bedding constant means that the bedding yields little, and a low bedding constant means that it yields easily. The yield under a circular pipe is the result of compression of the soil layers under the pipe and a kind of incision process. In fact the soil underlying is failing in a continuous manner, causing the width of the loaded soil surface to increase (increasing bearing angle $\beta = 2\beta$ In a sufficiently firm soil the bearing angle will be small. Loosening the soil, making it less firm over a certain depth, will increase the bearing angle. In a less firm soil the bearing angle as a result of the load will increase rapidly. If we expect a situation in which the pipe will continue to sink as a result of the structural failure of the soil under the pipe, a foundation on piles will have to be used. To avoid this a lightweight pipe of plastic can be used instead.

Natural foundation
This type of foundation has been discussed and explained in detail in an earlier part of this chapter. It is used when cone penetration tests indicate that the soil offers sufficient support.

Figure 6.43 Failure of the soil under the pipe

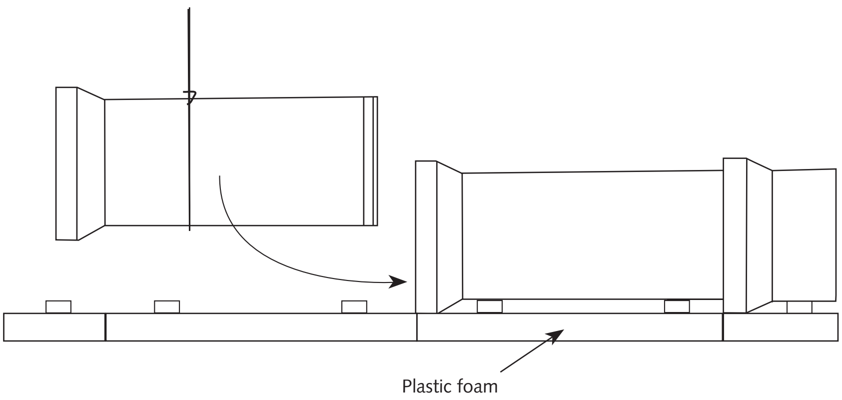


ASSIGNMENT
Can you name the situations that can occur with regard to the support in the soil of a loaded pipe?
We can have either of two situations:
- *The soil is sufficiently firm and there is no risk of the soil under the pipe failin*
- *The soil is insufficiently firm, and the soil under the pipe will fail to offer support. This will cause the pipe to settle. If there is a risk of extreme settling, the sewer will have to be supported by piles.*

Foundation on load-spreading layers

This type of foundation will usually be applied in locations in which very irregular settling can be expected and soil improvement offers insufficient hope of smoother settling. The result is a type of floating foundation. The pipes are flat-bottomed or are laid on timber chocks to keep the pipe sockets free from the support layer. The location of the chocks must be calculated in advance and the pipe must be suitable for laying on chocks. Non-socketed pipes must be provided with good bedding along the underside. This can be achieved for example by adding stabilised sand or tamped concrete along the pipe base.

Figure 6.44 Foundation on plastic foam blocks [VPB]



Foundation on piles – application and design limits
Foundations on piles are used if the pipeline construction, in combination with the soil structure, makes it necessary. This is assessed on the basis of a soil survey. Pile foundations are used mainly in locations where the subsoil contains peat layers. Even so a solution that does not require pile-driving is much preferred for the following reasons:

- Pile-supported structures are expensive
- Pile foundations may cause ridges to form in the road along the sewer route
- Transitions between pile-supported sewers and other sewer types often cause problems
- Connection pipes to properties require special precautions

Pile-supported sewers require pipes of sufficient strength. Earlier in this section you saw that as a result of the rigid foundation the resulting loads can be considerable. This results in relatively heavy pipeline structures. You must also be careful when designing the connection of a pile-supported sewer to another sewer that is not supported on piles. The transition should preferably be flexible and use a short pipe section. Another solution is to support the end section of the unsupported sewer on piles that become gradually shorter as they are further away from the connection to the other sewer. See also figure 6.45.

ASSIGNMENT
What causes ridges to form in the road surface above sewers supported on piles?

Since the sewer is supported on piles, it is a rigid element that will not settle. Under the load of traffic the soil on either side of the pipe will gradually settle. The difference in settling causes the road surface over the sewer to sit higher and this can be seen as a ridge in the road.

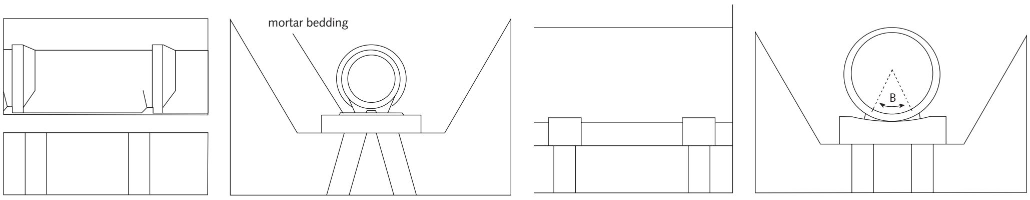


Figure 6.45 Concrete sewers with flat base on a continuous concrete floor foundation, and a foundation of concrete chocks with circular pipes [VPB]

6.3 Realisation of sewer systems
This section discusses how sewer systems can be realised. In subsection 6.3.1 you will learn how to construct new sewer systems and what is needed. Once the sewer system has entered service, there will come a time when the system no longer satisfies the current requirements. That is the moment to start improving the existing sewer system, a subject that is discussed in subsection 6.3.2. This section concludes with section 6.3.3, which looks at the construction techniques and the related issues.

6.3.1 Construction of new sewer systems
New sewer systems are constructed in the following situations:

- In a newly developed area
- In a redeveloped area

The latter situation occurs when in an existing area all the streets and buildings have been removed, or when the infrastructure and buildings in an old quarter have been completely or partially removed to be rebuilt according to new principles.

In newly developed areas a sewer system must be constructed of the improved separated type, or a sewer system in which the foul water and rainwater will be carried off by separate sewers. The environmental impact of the latter type of sewer system must be the same as that of the improved separated system. This section will be based on an improved separated sewer system.

The new sewer systems will either have to be connected to an existing sewer systems, or discharge directly into a sewage treatment plant.

In the second case, the area is often small to medium-sized, or in an old quarter in which a new sewer system needs to be constructed. Section 6.2.1, Sewer system design, outlined the options for a new design. It doesn't matter whether we're dealing with a new development, a small-scale redevelopment, or a complete makeover of an old quarter.

You start with the design of the sewer system that is fixed on paper. How do you go about realising that sewer system? First you prepare the area for building, and then you make the area suitable for habitation.

Preparing for building
Preparing an area for building means creating a situation that enables the builder to start building houses. In a new development area new site levels may have been fixed, and a decision will have been made whether the overall site level should be raised or not. Raising the level of the entire site usually takes place before the sewer system is constructed. If the trench method is to be used, the construction takes place at the same time as the other work to prepare the area for building, e.g. the sewer system and water features. Of the new sewer system to be constructed at this stage, the main sewers with the connection points and the risers of the property connection pipes are constructed. If a new sewer pumping installation is needed, it will have to be built. The manholes constructed during this phase usually aren't completed up to ground level, but covered underground. Once this stage has been completed, the construction site access road can be laid. Prior to this, the utility companies will have laid cables and pipes. That is all that will be built during this phase.

Now the moment has come for the building contractor to start work. This gives you the time to start thinking about the next phase, which involves preparing the site for habitation. This means that the zoning plan will have to be worked out in detail. Depending on the progress of the construction work and the size of the development, this will take between six months and a year.

Preparing for habitation
At this point you will have to check the quality of the sewer system that was constructed and completed during the previous phase. A video inspection will be carried out to see if the building activities have caused any damage. It is important to carry out the inspection before the road is paved. Any defects to the sewer system will now have to be repaired. At this stage the properties will be connected to the risers that were installed on the sewer system during the previous phase. The rainwater gullies are installed and connected to their risers. The manholes will now be completed up to the road level, and the manhole covers installed. This completes the sewer system. It is important to make sure there is no sludge in the sewer system, and the best time to do this is before the rod is paved. In the mean time all the other work is carried out, such as laying the final paving and installing the street lighting and other street furniture. Depending on when the site is being prepared for building, the vegetation can now be finished, and trees planted.

6.3.2 Improving existing sewer systems
The purpose of improving existing sewer systems is to get rid of any bottlenecks that affect the system's hydraulic and environmental performance.

To find out which bottlenecks we can encounter in a given sewer system we shall first have to make an analysis. This is done on the basis of the functional requirements in combination with a Basic Sewer System Plan. The requirements are an elaboration of the objectives described in the Municipal Sewer System Plan. The functional requirements describe the desired situation. When preparing a Basic Sewer System Plan we look at both the hydraulic and the environmental performance of the sewer system. In the analysis the results of the calculations in the Basic Sewer System Plan are compared with the previously defined functional requirements. Any discrepancy indicates a bottleneck in the sewer system. Table 6.3 show a matrix of the possible bottlenecks in a sewer system relative to the functional requirements. Any measures to counteract the bottlenecks are aimed primarily at improving the performance of the sewer system.

Possible bottlenecks	**Functional requirement (desired situation)**							
	Sufficient wastewater discharge capacity	**Sufficient discharge capacity to prevent flooding**	**Wastewater arrives at treatment plant without excessive putrefaction**	**Free flow**	**Acceptable sedimentation**	**Waste overflow related to function allocated to soil/water**	**Water overflow related to receiving capacity**	**Control over water flows**
Insufficient foul water discharge	•				•			
Insufficient foul water discharg		•			•			•
Insufficient rainwater discharge capacity			•			•		•
Sub-optimal treatment plant performance	•	•	•		•			
Incorrect transport system dimensions				•	•	•		
Increased risk of pollution/damage				•	•		•	
Insufficient surface water receiving capacity							•	•
Insufficient space								•
Non-sustainable use of water								•
Abnormal system behaviour								
Insufficient system utilisation		•				•	•	•

Table 6.3 Possible bottlenecks in a sewer system relative to the functional requirements [RIONED Foundation, Urban Drainage Guideline module B1200]

To solve the bottlenecks, various different measures can be taken. Some are limited to a single bottleneck, such as a peripheral facility (storage/settling basin) that is unable to cope with the waste discharge. Others can affect several bottlenecks, e.g. disconnecting an impervious surface. It may be necessary to combine several solutions. Below are some examples of possible solutions resulting in improvements to sewer systems.

- With regard to dimensions and structure:
  - Increasing hydraulic discharge capacity
  - Altering transport system dimensions
  - Improving the wastewater discharge structure
  - Disconnecting injections into sewer systems
  - Separating sewer functions
- Disconnecting impervious surfaces
- With regard to storage capacity and peripheral facilities:
  - Construction of peripheral facilities
  - Construction of storage facilities
  - Changing the storage capacity
- With regard to overflows:
  - Relocate, modify, or remove external overflows
  - overflow pumping

- Modify the excess pumping capacity
- Introduce Real Time Control (RTC)
- Conversion of sewer systems:
  - Conversion from combined to improved separated sewer systems
  - Improvement measures in separated sewer systems
  - Improvement measures in improved separated sewer systems
- Cleaning, repair, renovation, and replacement of sewer systems.

A number of these solutions will now be discussed. The application of the unspecified solutions depends mainly on the local situation. If you would like to know more, you can find the information in module B1200 of the Urban Drainage Guideline published by the RIONED Foundation (www.rioned.org)

Increasing the hydraulic capacity
The capacity needs to be increased if a lack of capacity causes flooding. Depending on the location of the capacity problem in the sewer system other locations in the sewer system may suffer from other problems, such as more frequent and larger overflows. It is therefore preferable to consider the effect on overflows before applying such measures. If the effect on overflows is detrimental, you will have to see which other measures need to be taken. The implementation of such measures will preferably take place at the same time that the sewer is replaced.

Altering transport system dimensions
The transport system is the pressure pipeline of the sewer pumping installation.
The length of the transport system, the flow speed, the diameter and the resulting transport time and possible sedimentation of sludge can cause problems at the treatment plant, at discharge points in the sewer system, and in the pressure pipeline itself. We can minimise the problems by ensuring that the flow speed at maximum pumping capacity is sufficiently high.

The following example shows how the right choice of flow speed can reduce the transport time of the sewage in the pressure pipeline. The pressure pipeline has a length of 8 km and the flow rate is 0.50 m/s.

At 0.50 m/s the time it takes the sewage to pass through the pressure pipeline is roughly 4.5 hours. Increasing the design velocity to 1.25 m/s will reduce the time in the pipeline to about 1.8 hours.

A careful choice of dimensions in combination with the right transport speed will result in a considerably reduced stay in the pipeline.

Improving the polluted solids discharge structure
An inadequate discharge structure in a foul water situation can result in major accumulations of solids inside the sewer system. These accumulations of waste form a potential source of pollution in the event of an overflow. Improving the discharge structure is a possible solution.

An inadequate discharge can occur for example if the switch-on level of the sewer pumping installation is set so that a significant storage of dry weather discharge is created in the sewer system. Water boards often want to control the flow into the treatment plant by switching off sewer pumping installations. This causes the flow to slow down, or even become stagnant, so any solids in the sewage will settle. The resulting sludge can adversely affect the pollution level in the event of an overflow. Another drawback of an excessively high switch-on level in pumping installations is that putrefaction of the waste can occur, which can lead to odour and corrosion problems.

Relatively simple improvements in the sewer system with regard to the dry weather discharge include:
- Removing loops by adding sills that guide the wastewater in the desired direction
- Adding or improving
s in manholes
- Careful selection of pressure pipe discharge points into gravity sewers
- More frequent cleaning of sensitive locations such as culverts, constricted sewers and discharge limiters
- Removing lost storage capacity (unevenly settled or incorrectly constructed sewers) and back-flowing sewers.

The above measures are directly related to the object-focused measures, and so can be implemented at the same time. See chapter 7, Sewer system management.

Disconnecting injections
Injections are single-point discharges by commercial or industrial parties, a pressure sewer system, or some other sewer system or pumping area. If a combined sewer system become overloaded as a result of this type of discharges, rainfall can cause excessive waste discharges. One solution could be to reduce the load in consultation with the discharging parties, e.g by making arrangements about the discharge times. It is also possible to call permit holders to account regarding the permit's discharge conditions, i.e. by enforcing the permit. In some cases injection points may need to be moved or even disconnected.

In a separated sewer system too the foul water sewer can become overloaded, in particular if rainwater has incorrectly been discharge into the system. In such cases a hydraulic improvement measure is called for. The available options are identical to those outlined for the combined sewer system.

Pressure sewer systems used to be controlled by means of time switches, but telemetry systems are increasingly being installed, both in pressure sewer systems and in sewer pumping installations. They enable us to control the wastewater flow to some extent, and in fact optimise the available capacity.

When evaluating existing designs of gravity foul water sewer systems, as a rule a maximum acceptable filling level of 30% to 50% is maintained to ensure that the shear stress can be overcome. In practice, this is often difficult to achieve in the initial sections of the sewer system, which is why the initial sections should preferably be constructed using small diameter circular pipes, e.g. 200 mm.

Annexe 1 to the Urban Drainage Guideline module B2100, 'Summary of design principles for functional design' (*Samenvatting ontwerpgrondslagen voor functioneel ontwerp*) includes B1.5, which for a number of standard pipeline diameters gives the required minimum gradient for sewers in dry weather conditions. These are based on the minimum shear stress, the resulting filling level percentage, and the flow speed in the sewer system. These tables can be used for an initial evaluation. If a more detailed assessment is needed, a calculation will have to be performed.

Separation of sewer functions

Research has shown that the combined functions (transport, collection, and storage capacity) of combined sewer systems encourage the settling of sewer sludge in the sewer system.
Measures to achieve a separation of the sewer discharges include:

- Lowering the sewer pumping installation and adding a storage transport sewer near the sewer pumping installation. This will improve the discharge conditions for the upstream sewer system;
- Adding a smaller diameter collection sewer parallel to the main transport sewer. The main transport sewer is then used only during periods of rain.

Disconnecting impervious surfaces

One way to improve a sewer system is to disconnect rainwater from the sewer system. However, disconnection should not be undertaken without previous investigation to see how much water can be disconnected. Once this become clear, we must find out how the rainwater can be transported, infiltrated, or retained.

If we are to make well-considered choices, we shall also have to find answers to a number of questions such as:

- Is there surface water nearby into which rainwater can be discharged?
- Is there a soil survey that shows a sufficiently low groundwater table, and is the soil sufficiently permeable?
- What is the effect of disconnection and infiltration on the groundwater table, and are there any possible adverse effects outside the area to be disconnected?
- Is the soil or the groundwater polluted?
- Is there a drinking water protection area nearby that makes disconnection impossible?
- Is infiltration in green areas possible?
- Do we need to construct infiltration sewers?
- What does the Municipal Sewer System Plan say about disconnection?
- What are the costs of disconnection?

As you can see, quite a few matters must be cleared up first. You will also have to see how much, if anything at all, disconnection contributes to reducing the emission of pollutants. Storage/settling basins are built to reduce the emission of pollutants as a result of overflowing water. Disconnection reduced the precipitation load on the sewer system, so storage/settling basins can be smaller.
To help formulating disconnection measures, you can use a decision tree. Each water board uses one for disconnecting rainwater. It is like a flow diagram that guides you to the various different solutions that are acceptable to the water board.

Once everything is sufficiently clear we can prepare a Disconnection Plan. A Disconnection Plan indicates where disconnection may or may not succeed. In addition it shows where further investigation is needed. It is important to include a financial section listing the probable costs, and the should also include a proper planning. We need this because full disconnection usually is a long-term solution. This is because disconnection will only be successful if the procedure has been properly synchronised with the other measures to be taken in the sewer system.

Construction of storage and peripheral facilities
Storage and peripheral facilities have been discussed in detail in section 6.1.7. In sewer systems the most common facilities are:
- Storage facilities:
  - Storage capacity outside the sewer system
  - Storage capacity within the sewer system
  - Green storage capacity/flexible storage capacity
- Peripheral facilities:
  - Storage/settling basin
  - Storage/settling sewer

The purpose of storage facilities is to slow down the discharge of precipitation, and to reduce the discharge into surface water. A peripheral facility is an 'end of pipe' solution with both acts as a storage facility and reduces the discharge of pollutants.

Conversion of sewer systems
Combined sewer systems can be converted into improved separated sewer systems. Separated sewer systems can also be converted into improved separated sewer systems, for example at industrial estates.

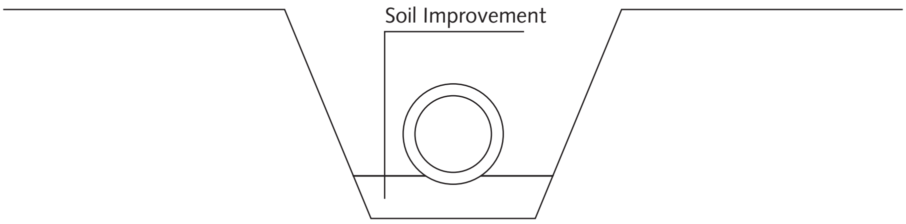
If the overflows in an improved separated sewer system discharge into vulnerable water, we can increase the storage capacity, add peripheral facilities, or disconnect the rainwater to improve the quality of the water discharged from the overflow.

6.3.3 Construction techniques and issues
This chapter concludes by looking at the construction techniques and issues involved in building sewer systems. We shall first look at the excavation and backfilling of the trench and the laying or installing of:
- Concrete pipes
- Plastic pipes
- Clayware pipes
- Concrete, plastic, and clayware manholes
- Connecting pipes
- Gullies.

Finally, we will look at the cables and pipes, trench shuttering, drainage, sewer system levels, and health and safety aspects.

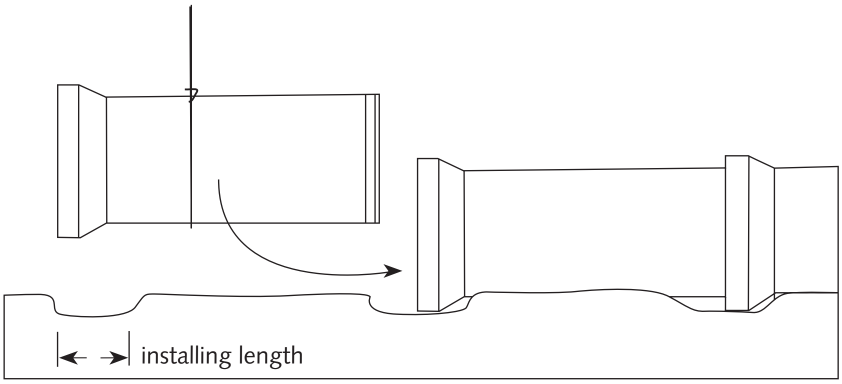
Laying concrete pipes
The trench must be excavated evenly and must not be dug too deep, or uneven settling may occur later. In a sandy soil the bottom of the trench right under the pipe must be loosened to create a good bedding for the pipe. Careful backfilling and compaction of the soil between the trench bottom and the pipe will also ensure that the bedding offers good support. In non-sandy soil good bedding support requires that sand be added to improve the soil.

Figure 6.46 Soil improvement under the pipe [VPB]



Soil improvement down to 0.20 m is sufficient. A good bedding means that after backfilling a large supporting surface (large bearing angle) has been created. A large supporting surface means better support for the pipe.

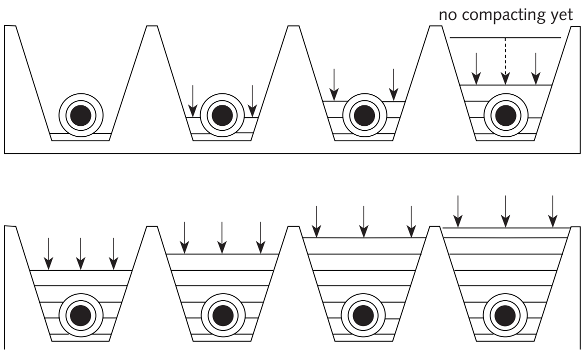
Figure 6.47 Accommodating the pipe sockets in the trench bottom [VPB]



The actual bearing angle must match the angle used in the calculation of the pipes. The trench bottom must also be deepened in places to accommodate the pipe sockets. For the remainder the trench bottom must be finished so that the pipe is supported by the soil along its full length.

The material for the lower and upper bedding of the pipe must not contain any rubble or other hard objects that could create a point load on the pipe wall. The pipe must be evenly loaded by the surrounding soil, so it is important to backfill the sewer trench layer by layer at a maximum of 0.20 m to 0.50 m per layer to ensure the soil can be well packed and compacted. Backfilling the trench must be done simultaneously on both sides of the pipe to prevent any sideways movement of the pipe (deviation from the centre line) or overly deep local settling of the section (deviation from the pipe gradient agreed in the contract). Figure 6.48 illustrates the backfilling method.

Figure 6.48 Excavating the trench and laying the sewer; method of backfilling the sewer trench



A concrete pipe is a rigid pipe. The settling behaviour of the backfilled soil surrounding the pipe determines the load on the pipe: low compaction increases the load on the pipe. Therefore, proper compaction is essential.

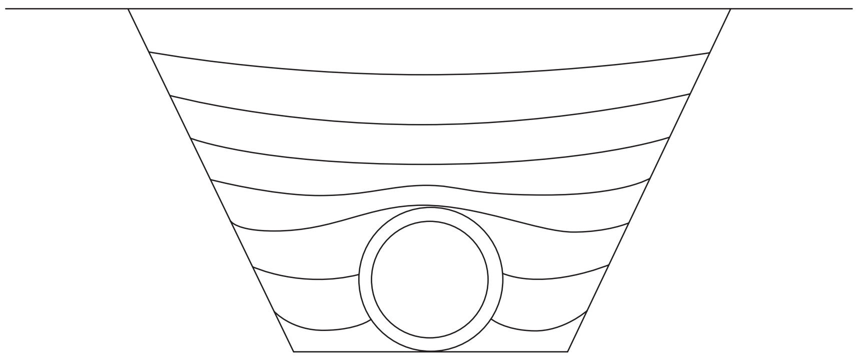


Figure 6.49 Rigid pipe soil load diagram [VPB]

Before backfilling the trench the backfill material in combination with the local moisture level may be subjected to a Proctor test to get an idea of the maximum possible density (compaction). After backfilling and compacting, the soil structure in the trench must be tested using one of the following methods:

- A hand-held cone penetration test device
- Cone penetration tests after compaction
- Random Proctor tests on a backfilled layer

A hand-held cone penetration test device will give a quick reading of the compaction, but the results depend on how the device is pressed into the soil. The other methods are reliable, but have the drawback that the results can take a while.

Pipes to be laid must be lifted safely and in accordance with the regulations, observing the following rules:

- Large pipes must be suspended from at least two slings
- When using slings and pipe hooks these must be attached so that the pipe hangs horizontally and remains in balance at all times
- The pipe must not be able to slide in the sling
- Any hoisting points provided by the manufacturer must be used and stressed evenly

See figure 6.50.

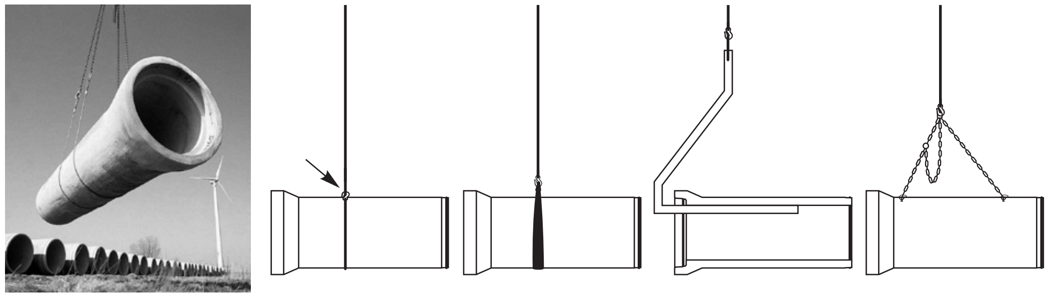
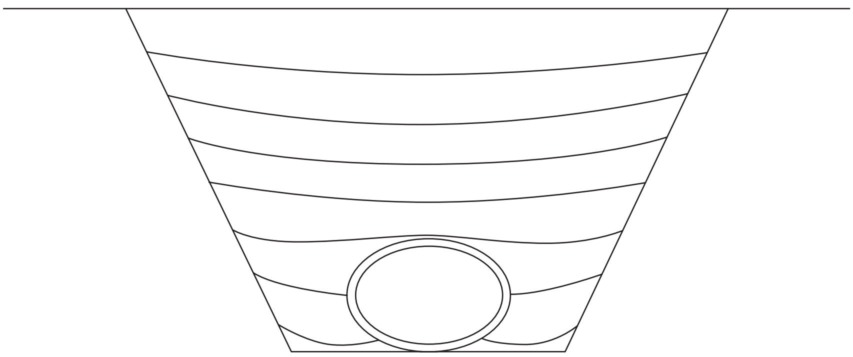


Figure 6.50 Concrete pipe suspended from two slings [Betonplaza] and hoisting facilities for smaller pipes

Laying plastic pipes
Most of the issues related to excavating and backfilling a trench for concrete pipes also apply to plastic pipes, with additional emphasis on the need to make sure that material used for backfilling under and around the pipe must not contain any rubble or other hard elements.

Since plastic pipes are flexible pipes, their behaviour in the backfilled trench is fundamentally different. The settling soil around and above pipe constitutes a load on the pipe, causing the pipe to become slightly oval, which reduces the load on the top of the pipe while increasing the load on the soil next to the pipe. This causes the soil alongside the pipe to be compacted, further increasing the counter-pressure against the oval pipe, which will prevent the pipe from deforming any further.

Figure 6.51 Flexible pipe soil load diagram [VPB]



Since the load is being transferred to the surrounding soil, low compaction next to the pipe will result in insufficient pressure to support the pipe wall, which will become even more oval. Proper compaction is therefore essential.
The compaction, the type of backfill, the pipe depth, and the pipe's stiffness class must all work together to keep the deformation of the pipes within the acceptable values.

Apart from the essentially different way flexible pipes behave when compared with concrete pipes there are a number of other issues that must be addressed. The larger length of the plastic pipes means that the trench bottom will have to be finished accurately with the specified gradient and with an evenly compacted soil in order to ensure good flow characteristics. Checking the level regularly is recommended.

When compacting the soil alongside the pipe care must be taken not to dislodge the relatively lightweight pipe. For PVC pipes without a factory-moulded socket there is no need to excavate the trench bottom for the coupling sleeves, since they are relatively thin. For pipes with factory-provided sockets on the other hand, the trench bottom must be pre-shaped.
The pipe must be capable of withstanding both the external load and the internal pressure, taking into account the soil quality. The pressure class must be as specified. The trench may not be left open too long, for rain and low soil permeability can easily result in a floating pipe.

Laying clayware pipes
The issues involved with excavating and backfilling apply equally to clayware pipes. The behaviour of the pipe in the soil is comparable to that of a concrete pipe, but a ceramic pipe is slightly less rigid than a concrete pipe. Clayware pipes with sockets are comparable to concrete pipes, and unsocketed clayware pipes are comparable to unsocketed plastic pipes as far as the coupling is concerned.

When clayware pipes are cut to length, cracks can form, caused partly by the stresses induced in the pipe wall by the firing process.
Care must be taken to properly store and process the ceramic material. Make sure in advance that the pipe is intact and shows no cracks. This can be done by simply tapping a small hammer against the pipe. A clear sound indicates that the pipe is intact, whereas a dull sound indicates that the pipe has formed a cracked.

The installation of manholes in gravity pipes

Concrete manholes
If the connecting pipeline lies considerably higher than the lower edge of the manhole, care must be taken not to create a rigid joint with the manhole, otherwise settling differences might well cause the pipeline to crack at the manhole. The use of a flexible joint consisting of a rubber ring or a concreted-in or bricked-in short butt end prevents this problem. This type of solution must always be used at the transition from a pile-supported sewer to a naturally-supported sewer. The sewer must be connected to the butt end by means of a short pipe section known as a rocker pipe. In situations like these care must be taken to properly compact the backfill material. The addition of stabilised sand under the pipe can prevent problems in the longer term. When installing prefabricated manholes, the trench bottom at the projected manhole location must not be excavated or finished too deep, or the manhole may end up more or less suspended from the sewer pipes.

Plastic manholes
Plastic (polypropylene, PP) manholes often come as all-in-one units. Around the top section a concrete slab is laid to receive the regulating layers and the manhole cover in the same way as for prefab concrete manholes.

Manhole covers
Depending on their location, manhole covers must be capable of withstanding heavy or light traffic. If there is a risk of sewage emerging from the manhole, a secured cover can be used, which is screwed down in the manhole rim. Of course, the underlying structure must be capable of preventing the top of the manhole being blown off by the pressure from the accumulated water and air.

Laying connecting pipes
In many cases additional property connection pipes will have to be installed. This can be a problem, since the public area underground already contains all kinds of cables and pipes. Often neither the location nor the depth of these cables and pipes is what was arranged and what is indicated on the drawings. A common enough situation is when a property's front wall directly faces the public highway. In addition, as a result of alterations over the years to these buildings it may be difficult to be certain which pipes there are and what their functions are. This often makes it difficult to decide what kind of connection is to be made. The picture below shows the kind of situation that may be encountered.

Figure 6.52 Example of a complex property connection [Tauw]

Where properties need to be connected to the sewer so-called settling sleeves must be included in the riser just above the inlet to the sewer. The purpose of these is to prevent a reverse gradient from forming in the section of pipe leading from the property boundary or the gully. The settling capacity included in the riser must match the amount of settling that may occur after the property connection to the riser is established. Of major importance in this respect is whether the property connections to the risers are made immediately after building the transport sewer, or at a later time, e.g. once construction has been completed. The following guidelines apply.

- Connection immediately after building the transport sewer
  - Concrete sewers: settling 1/10 – 1/20 or pipe diameter + riser length
  - Plastic sewers: settling 1/10 – 1/20 or the riser length
- Connection at a later time
  - Concrete sewers: include settling capacity (T-joint or sleeve with settling capacity) if pipe diameter + riser length ≥ 1.00 m
  - Plastic sewers: up to a riser length of 1.50 m the settling capacity offered by the screw or lever inlet adapter with settling sleeve is sufficient. For longer risers additional settling capacity must be added.

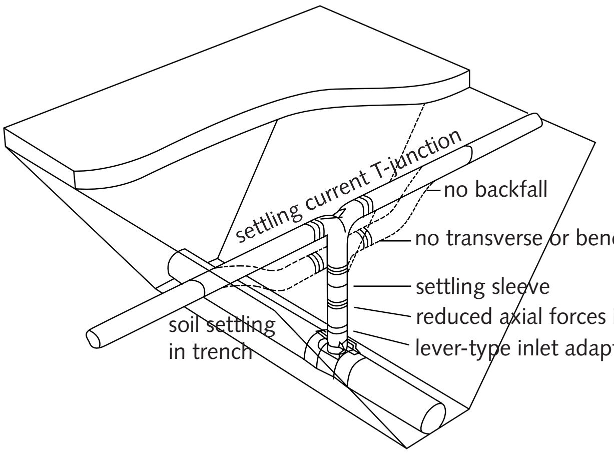


Figure 6.53 Property connection pipe with settling sleeve to prevent back fall [Wavin]

If the sewer lies very deep, or if its diameter is very large, it is better to lay a parallel sewer to which the properties can be connected. This parallel sewer can be laid either above or to the side of the transport sewer and must be connected to the nearest manhole or manholes. If the existing sewer lies under the groundwater table, a parallel sewer can also offer a simple solution because it does not need to be laid so deep. If the groundwater table is very high you will have to temporarily lower the water level by pumping before the new connections can be made.

The installation of gullies

Gullies are installed while the road is being constructed. All soil is backfilled to the required level, and the kerbs are laid. Where gullies are to come, gaps are left in the kerb line, and soil will have to be removed to accommodate the gully. The gully assembly is then set in place and connected to the previously installed discharge pipe. See figure 6.54.

Figure 6.54 Gap in the kerb line to accommodate gully.

Section 6.1.4 shows how the connection to the discharge pip must be made. Only very little space remains around the gully once it is in place, making it difficult to properly compact the soil. Very often the paving around the gully will subside, causing water to remain on the road.

Cables and pipes

When sewers are laid, existing underground cables and pipes will always be encountered. These include the following.

- Low-voltage and high-voltage power cables
- Telephone cables, fibreglass cables for data traffic, signalling cables, coaxial TV cables
- Local and national gas transport pipes
- Local and regional water transport pipes
- Wastewater transport pipes
- Sewers
- Cooling water pipes
- Oil pipelines
- Pipes of which the function and the management authority are unknown (orphan pipelines)

All these pipes are managed by different management authorities. Each pipeline management authority will have developed its own system for keeping track of pipes using drawings. Horizontal and vertical distances must be accurately recorded. In addition widely varying conditions may apply with regard to working in the vicinity of pipes according to the media they contain.

Since in many cases the quality of the drawings provided by the pipeline management authorities will be insufficient, survey trenches will have to be dug to ascertain the location and depth of existing pipelines. In some cases the use of ground radar may offer a solution, but it certainly cannot replace the digging of survey trenches altogether.

Some 40,000 digging incidents every year

Digging operations are often marred by incidents, which can cost a lot of money. Research has shown that the resulting direct damage to cables and pipes ranges between 40 and 75 million euros a year. In addition to the economic damage the cable or pipeline suffers, digging incidents also interrupt the supply of gas, electricity, or telecom signals. Digging incidents can also threaten the life of the digger and those in his vicinity.

Cable and pipe defects in development areas.

In practice, 65% of the defects affecting cables and pipes are the result of groundwork in development areas for which the final version of the Large-scale Standard Map of the Netherlands (*Grootschalige Basiskaart van Nederland, GBKN*) has not yet been compiled. The area will not yet have a uniform topography, so each management authority will be using its own measuring system. This means that the dimension plans cannot be stacked and cannot be easily read. In addition, there is a lack of uniformity for surveying cables and pipes.

In order to minimise the number of defects and incidents new legislation was adopted on 1 July 2008 in the form of the Underground Networks Information Exchange Act (*Wet informatieuitwisseling ondergrondse netten, Wion*), see www.ez.nl/Onderwerpen/Overig/Grondroerdersregeling. The act, which lays down obligations for every management authority of cables and pipes, is also known under the name excavation regulation (*Grondroerdersregeling*).

For information about the location of cables and pipes we can consult the Cables and Pipes Information Centre (*Kabels en Leidingen Informatie Centrum, KLIC*), see www.klic.nl. This organisation operates a digital system for exchanging data between network management authorities and excavators. With the adoption of the Underground Networks Information Exchange Act the Cables and Pipes Information Centre passed over to the Land Registry, which continued to develop the system, which is now fully operational. See www.kadaster.nl/klic. For digging operations, CROW has developed the Careful digging operations guideline (*Richtlijn Zorgvuldig Graafproces*) to complement the Underground Networks Information Exchange Act. Another authority active in this domain is Cables and Pipes Consultation (*Kabels en Leidingenoverleg, KLO*), which is a collaboration between network management authorities, excavators, and public clients, see www.graafschade-voorkomen.nl. Their activities are focused on reducing the damage caused by digging incidents in the Netherlands.

Trench shuttering

Once the projected sewer system reaches a certain depth below ground level, trenches nay not be dug without taking certain precautions. In this case the reason is safety, because there is always the danger of a trench wall collapsing. In addition to this there may be other reasons to fit shuttering to the trench. In the following cases shuttering must be fitted to a trench.

- The bottom of the sewer trench is too far below ground level.
- The soil structure is non-cohesive and presents a danger of collapse, e.g. peat, wet clay, runny sand.
- Lack of space requires that the trench be kept a narrow as possible (straight sides).
- There is traffic passing close to the sewer trench, increasing the risk of collapse of the sewer trench.
- The sewer trench needs to remain open for an extended period, increasing the risk of collapse and soil being washed away by rain
- Soil movement is to be minimised for environmental reasons, e.g. due to soil pollution.

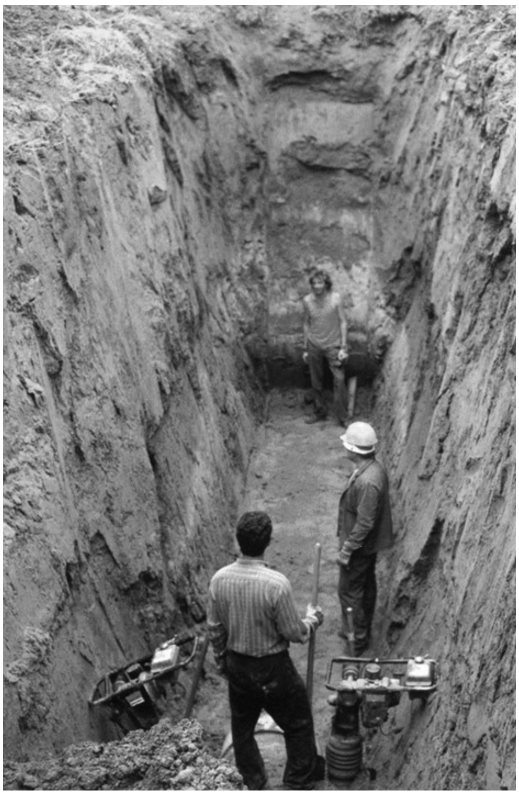


Figure 6.55 Sewer trench without and one with [VPB] shuttering

ASSIGNMENT

What strikes you as unusual in these two photos?
Photo on the left: the sewer trench is much too deep to work without shuttering. In addition the trench sides are much too steep, with a real danger of collapse with possible very serious consequences.
Photo on the right: the space between the sewer trench and the trench shuttering is far too wide. There is a risk of the trench wall falling in and dislodging the trench shuttering. The sewer worker is standing with one leg on the trench shuttering, risking a serious accident. In view of the depth of the trench the working space alongside the pipe is far too narrow, so the workers have insufficient room to move about.

There are various ways of fitting shuttering to a sewer trench. The choice of system depends in part on the local soil type, the depth of the sewer trench, traffic intensity, etc. It is essential to perform a thorough stress calculation based on a soil-mechanical survey. In addition, trench shuttering must comply with the applicable regulations and legislation such as health and safety. The following types of trench shuttering may be used.

- Steel shuttering and props
- Sheet piling, with props depending on the calculation results
- 'Berliner wall', a structure consisting of a combination of timber or steel lagging inserted between steel H-section soldier piles. In sewer trenches props are usually added between opposite piles.

Figure 6.56 Trench shuttering using steel sheet piling (Syncera) and a modern form of a 'Berliner wall' (Euros Verbau)

Structures such as these are usually limited to relatively small lengths of sewer. In addition, special provisions will often have to be made for crossing cables and pipes.

Dewatering

A sewer system must always constructed in dry conditions. If the groundwater table is too high, dewatering will be required. The groundwater must be extracted down to at least 0.25 m below the projected trench bottom level.

A dewatering plan should be prepared, based on a hydrological survey. The dewatering plan indicates how dewatering pumping is to take place and how much groundwater is to be extracted. This information is then used to decide whether a dewatering permit is required. The effect of the extraction on adjacent properties must be indicated. To avoid subsidence, any structures in the direct vicinity that are not supported by pile foundations must be monitored using water gauges. The dewatering plan also pinpoints any possible risks of damage to trees as a result of the groundwater extraction.

The quality of the groundwater must be known because of the restrictions that apply to the discharge of the extracted water into surface water or the soil.

The Groundwater act stipulates that a permit is required if construction dewatering extracts more than 10 m^3/h. The decision lies with the provincial authorities, who in their provincial regulations have included exceptions for construction sites. The permit requirement usually applies to long-term dewatering work only (over 6 months) or to very large pumping operations (more than 100,000 m^3 per month, for example). Whatever the case, any groundwater extraction must be reported to the provincial authorities. The procedure time for a permit is at least 6 months. Work must not be started without a permit.

The most common type of dewatering system is well-point drainage, which is used in soil types in which the groundwater moves vertically.

For sewer trenches two types of well-point drainage are common:
- Vacuum drainage
- Pressure relief drainage

Vacuum drainage is the most commonly used form of dewatering. Vertical filters are installed next to the construction site or sewer trench. A hydrojet is used to create a vertical hole in the soil. As soon as the hole reaches sufficient depth, the hydrojet is retracted and a filter inserted in the hole. Each filter is connected to a collection pipe laid on the soil next to the trench, which is connected to a vacuum pump, hence the name 'vacuum drainage'. The vacuum pump creates a low pressure in the filters, causing the capillary water to be sucked into the filter tubes, lowering the groundwater table. The filter consists of a plastic pipe with a diameter of 2 to 4 inches. The perforated lower section has a length of 1.0 – 2.0 m, followed by a closed upper section between 3.0 and 8.0 m long. The size of the perforations varies between 0.3 and 0.4 mm. The distance between the filters varies between 1.0 and 4.0 m. The filters are connected to the collection pipe in groups of 50 – 150. For sewer trenches the filters are usually located alongside one side of the trench, but for wide trenches they will need to be installed on both sides.

Pressure relief drainage is needed if there is an impervious layer in the soil below which groundwater pressure has built up. This can be verified by means of a water gauge, in which the groundwater level will rise above the impervious layer. To relieve the pressure we must insert deep filters and extract the water from a greater depth to avoid the risk of the trench bottom bursting under the water pressure during digging operations.

If the dewatering plan indicates any risks to adjacent properties, we can reduce the extent of the dewatering by installing the filters closer together and reducing their depth. In situations where such risks do not exist, filters may be placed further apart and sunk deeper. During dewatering operations care must be taken to ensure the survival of vegetation, and trees in particular. It is recommended that water gauges be installed to monitor the water extraction, so the pump system can be adjusted or modified should the groundwater table sink too low. The sketch in figure 6.57 illustrates the principle of vacuum drainage.

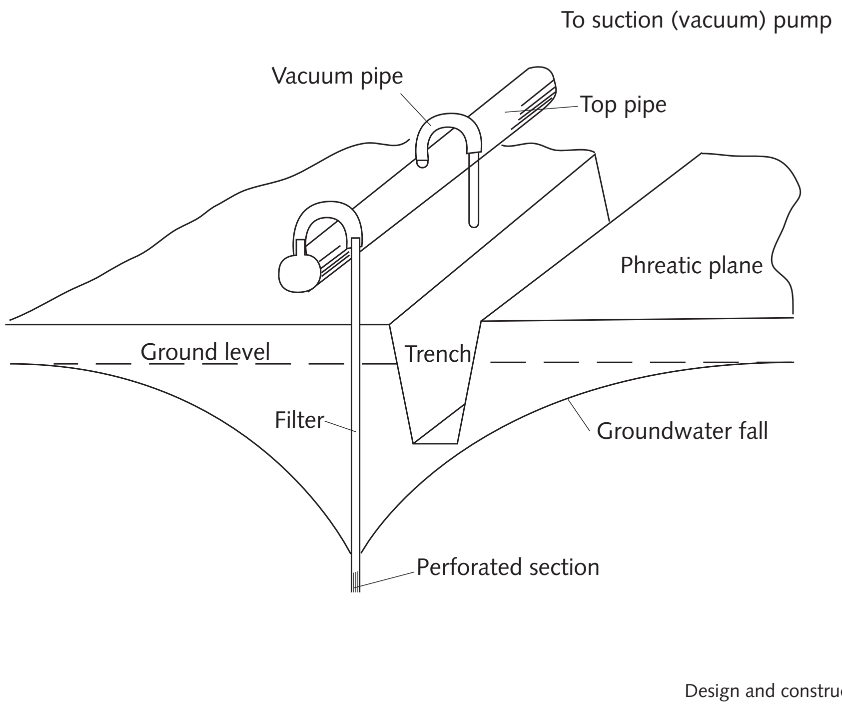


Figure 6.57 Lowering the groundwater table using vacuum well-point drainage

The picture in figure 6.58 shows an example of vacuum well-point drainage.

Figure 6.58 Well-point drainage using a vacuum pump

Care must also be taken to ensure the noise level of the pumping installation complies with national legislation and local regulations, both during the daytime and at night.

In order to reduce any risk to the projected work, a reliable system must be installed. If necessary, automatic backup pumps and/or power generators must be included. The cost of a backup system must always be weighed against the benefit it brings.

When the dewatering installation is removed, care must be taken to ensure that the filter locations (wells) are properly filled using bentonite (a very fine type of clay) to prevent subsequent flooding problems. The bentonite seals the artificial leaks created for the dewatering system, and must certainly be used if any impervious layers were punctured or if there is any risk of seepage, due to high river levels for example. Another reason for making sure all holes are properly filled in is to prevent subsidence of the road surface.

Sewer system depth

A sewer system must always be laid out using one of the datum marks of the Dutch national vertical reference system (*Normaal Amsterdams Peil, NAP*) as a starting point, since the levels of manhole covers in roads may have changed over time. The site supervisor must ensure that the main dimensions are properly marked out on site.

Before commencing work, it is important to once again check the current level of the sewer system to which the new sections are to be connected. The levels of crossing pipes must also be taken into account. Better safe than sorry.

Survey trenches must be dug because the information provided by the Cables and Pipes Information Centre (*KLIC*) often differs from the actual situation. The course of the new sewer can still be changed before work is started, which is preferable to finding yourself in a situation with work in progress and little or no room for corrections.

The level of the pipes is set out using a laser levelling device. Make sure the laser is properly aligned, and check its adjustment regularly, at least once a day.

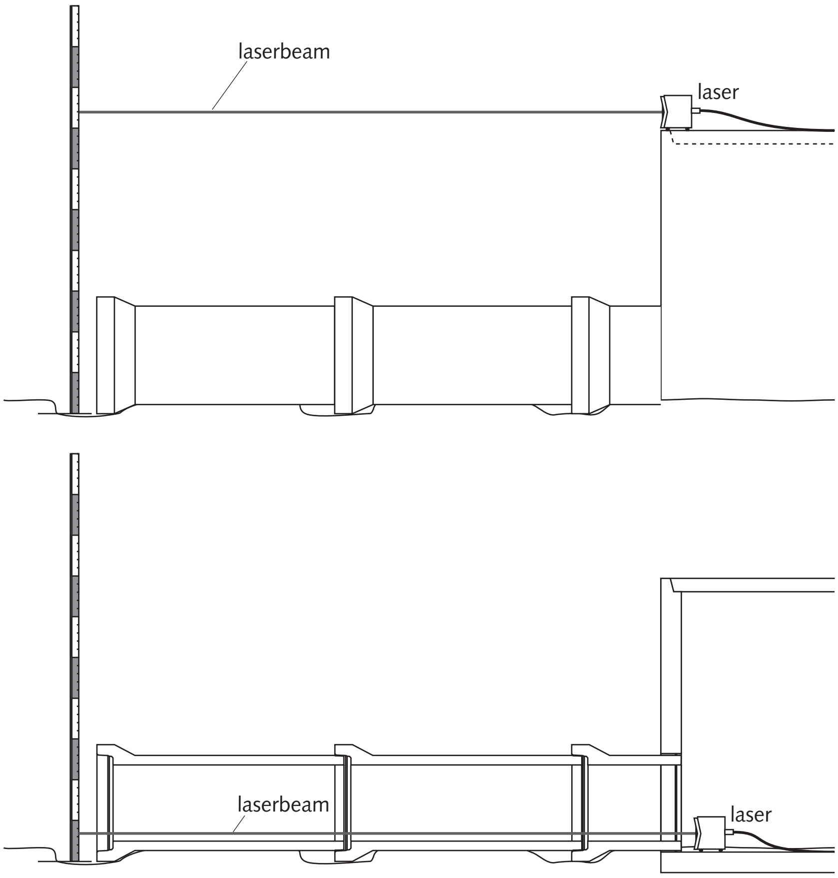


Figure 6.59 Laser levelling arrangement

The laser pointer must be kept stable and accurately levelled at all times, without being disturbed by work in progress. Do not place the laser pointer on a freshly laid pipe, as its setting will be disturbed as soon as the next pipe is laid.

One problem that requires special attention as the work progresses is that of incorrect levels between manholes. It is very annoying to have put a lot of effort into ensuring that the pipe levels are correct where they join the manholes, only to discover that the sections in between are incorrectly positioned, possible even creating backfall. The specifications must show how much the actual levels may differ from the theoretic gradient indicated in the construction drawings. It is essential that the specifications be followed to the letter if we are to avoid ending up with a sewer that's incorrectly laid.

Health and safety
Working on a sewer system always involves a certain degree of risk, whether from noxious fumes when entering the sewer, or from traffic accidents at roadworks.

The Health and safety act (*Arbo-wet*) is of major importance to a sewer management authority. Legally, the ultimate responsibility for construction site safety lies with the principal, which in most cases will be the sewer management authority. The law includes special provisions for high-risk categories of work wet, known as health and safety resolutions (*Arbo-besluiten*).

Figure 6.60 Safety grating under wet well hoist hatch

Health and safety resolutions exist for the following types of sewer work.

- Detailing of Risk Inventory and Evaluation (preparing a risk inventory, then using a documented procedure to perform an evaluation following which safety measures or regulations are drawn up).
- Working in confined spaces.
- Contact with biological agents (pathogens).
- Working on pumps and pumping installations.
- Dangerous drops, third-party traffic safety.

The Arbouw foundation publishes leaflets and provides information about these health and safety issues. Information sheets and leaflets can be downloaded from www.arbouw.nl/werkgever/beroepen-en-risicos

Self-assessment questions for chapter 6

1. Concrete, plastic and clayware sewer pipes are used in the Netherlands. What are the strengths and weaknesses of each of these types of pipe? Which type of pipe would be your first choice if you were looking for:
   - large pipe diameters;
   - small pipe diameters;
   - pipes capable of taking high traffic loads;
   - pipes for low traffic conditions;
   - pipes to be laid in sandy soil, clay, and peaty soil.
2. How are watertight joints created in concrete, plastic, and clayware sewer pipes?
3. How are gullies and properties connected to the sewer system? Include a sketch.
4. PVC sewers are available in the colours grey, brown-red, and green. What do these colours signify?
5. What is the function of manholes? What are the usual distances between manholes (i.e. the usual sewer section lengths)? Sketch the composition of a prefab concrete manhole and name its main components.
6. How does an odour screen in a gully work? Sketch a plastic gully and name its main components.
7. Sketch a sewer pumping installation with a wet pump arrangement, indicating and naming the essential components. Chapters 5 and 6 refer to adjustable-speed pumps in sewer pumping installations. In which type of sewer pumping installation of which type of sewer system are adjustable-speed pumps best used?
8. How do you prevent the receiving surface water from entering the sewer system through an overflow? Include a sketch. What are the consequences if the level of the receiving surface water rises above the level of the overflow sill?
9. Sketch a storage/settling basin and describe how it works.
10. Is a swale a green storage facility, or a storage facility outside the sewer system? Describe how a swale works.
11. What are the main considerations and options when designing an improved separated sewer system? (e.g. location of the sewer pumping installation, location of the overflows, the sewer route, the vertical and horizontal location, watertight pipes or IT-sewers).
12. A sewer section of a transport sewer has a length of 70 m. The sewer pipe is a circular section concrete pipe with D = 500 mm laid at a pipe gradient of i_b = 1/450. The invert level at the initial manhole is -0.84 m. Calculate the invert level at the final manhole.
13. What are the factors involved in the calculation of the soil load on sewer pipes?
14. The foundation pressure of a sewer pipe is determined by the bearing angle. Give an indication of the bearing angle of rigid and flexible pipes in soil with good load-bearing properties and in soil with poor load-bearing properties.
15. Why should you avoid the use of pile-supported sewers, if at all possible? What are the other available options?
16. What does 'improving' an existing sewer system involve? How (i.e. according to which procedure) are the improvement measures decided?
17. Which improvement measures are required to convert an existing combined system into an improved separated system?
18. Describe and sketch the main components and the operation of well-point dewatering. Where does the extracted water go?
19. Describe and sketch the laying and backfilling of a PVC sewer pipe on a sand foundation.
20. Why is it so important to make sure that the sand on either side of a plastic pipe is well compacted without changing the horizontal or vertical position of the pipe after laying?

21. Describe and sketch the laying procedure for large flat-based concrete sewer pipes in a busy shopping street with little room to manoeuvre. How do you check the vertical position of the pipes?
22. When excavating soil before laying a sewer it is important to know what may be lying underground. How do you find out?
23. An improved separated sewer system is to be constructed for a new development area. Describe the order in which the construction operations take place for the following components and how they relate to the construction of roads and buildings in the area: rainwater sewers, foul water sewers, manholes, connecting pipes, gullies, and property connections.
24. Work in the sewer systems industry, in particular when connected with construction and inspection, is subject to a number of health and safety resolutions. Name some of the safety aspects and risks involved.

7 Sewer system management

This chapter is about sewer system management. It will enable you to gain insight into the various activities that form part of sewer system management.
The following subjects will be discussed:
Section 7.1: Terms and definitions
Section 7.2: Strategic and policy activities
Section 7.3: Operational activities
Section 7.4: System and object management
Section 7.5: Operational management
Chapter 3 discussed how the management aspects have been implemented in municipal planning, how a municipal executive uses the planning instruments, and how the management side of things is organised. In this chapter we will look at the technical aspects of sewer system management: what are the process issues that stand out, what are the various activities, and what are the connections between them.

7.1 Terms and definitions

Managing a sewer system means making sure the system's performance criteria are met. If the management authority is the municipality, this involves the responsibility for all sewer system objects (sewers, manholes, pumping stations) located outside buildings in public areas (the outside sewer system) as well as the responsibility for the performance of the sewer systems system as a whole. The management of outside systems is described in the European standard NEN-EN 752. A great deal of this standard is based on the now retracted Dutch Code of Practice (NPR) 3220, which defined a framework for sewer management in the Dutch situation. In addition to defining a framework, NEN-EN 752 gives structure to the further standardisation of outside sewer systems in Europe. See the figure below.

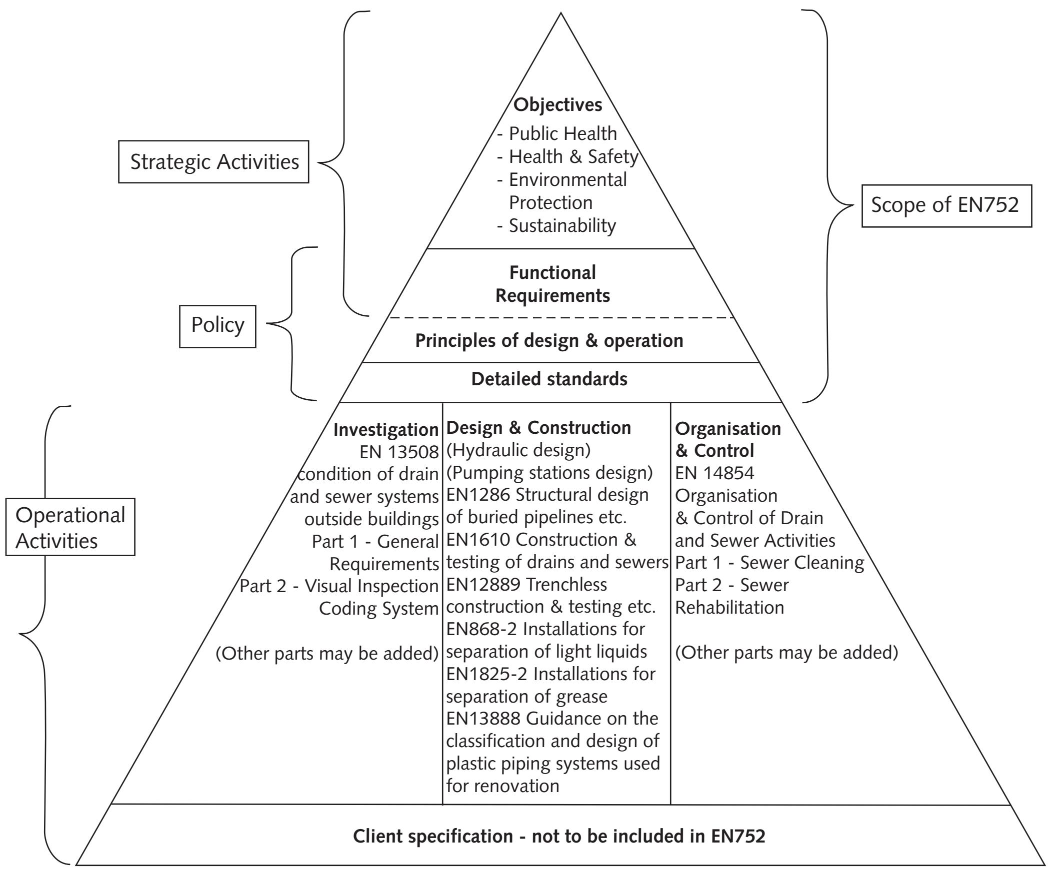
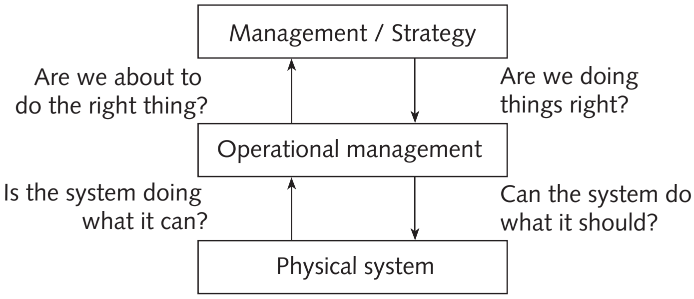


Figure 7.1 Structure of NEN-EN752 (source: NEN)

Sewer system management as discussed in this chapter refers to the management of municipal sewer systems as part of the statutory responsibilities.
Sewer system management consists of all the activities that are aimed at making a sewer system perform within previously defined limits (see figure 7.2).

- These limits are described in objectives, functional requirements and performance criteria, defined in a Municipal Sewer System Plan approved by the local council. Based on this plan both the performance of the sewer system as a system and the physical condition of the objects in the system are assessed, so focused management action can be taken. See Urban Drainage Guideline module C2100, C2400, NEN 3398;
- The purpose of the activities is to prevent the sewer system from operating outside its limits. This aim has been implemented at various levels within the municipal organisation. The local council is responsible for the policy framework. The mayor and aldermen are responsible for the implementation, while the civil service handles the policy preparation and the actual implementation.

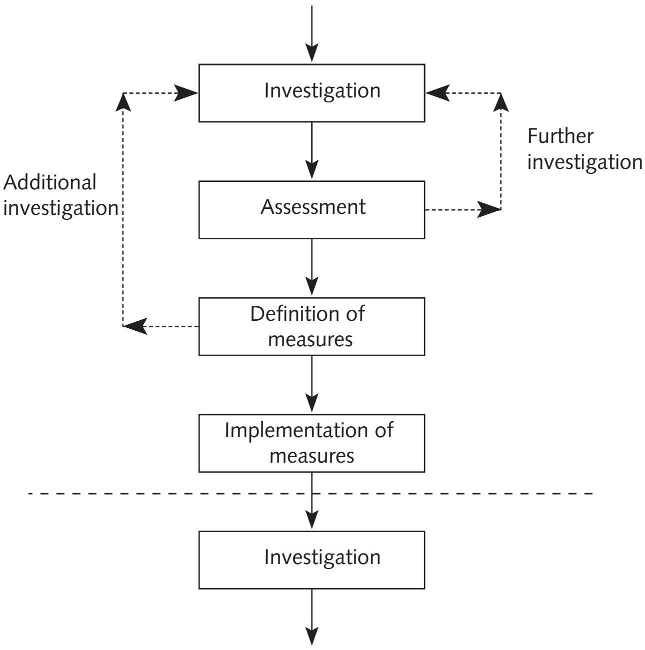
Figure 7.2 Performance of the sewer system (as a system) within defined limits (source: Geoplan)



The actual day-to-day implementation, the operational management, comprises four basic activities (see figure 7.3):

- Investigation
- Assessment
- Definition of measures
- Implementation of measures

Figure 7.3 Basic activities: the management process (source: NPR 3220)



The basic activities are cyclical in nature, so the activities always return in the same order. Operational management is aimed both at the performance of the system sewer system and on the condition of the physical objects in the system. If the object condition leaves something to be desired, this usually affects the performance of the system as a whole.

In this chapter we will concentrate on the activities in management that are aimed at the condition of the objects in the sewer system. The management activities aimed at the performance of the sewer system as a whole have been discussed in chapter 6.

The objectives, functional requirements and performance criteria form the instrument that is used to assess whether the policy frameworks, the strategy, and the operational management as defined by the local council have resulted in a working system. They enable the effects of management activities to be measured.

7.2 Strategic and policy activities

Strategic activities
A municipality has the statutory task of ensuring that any wastewater (including rainwater and excess groundwater) released within its territory is collected and disposed of. Sewer system management forms part of this management task. With the statutory expansion of the management tasks to include rainwater and groundwater, a de facto strategy has been created to define the municipal water tasks.
The local council outlines the municipal management task. Until recently this was referred to as the municipal sewer system strategy.

Examples of such outlines are:
- Over the next 10 years we will give absolute priority to remedying the recurring groundwater problems.
- We will replace the old sewer system only in combination with road reconstruction.

A municipal council must also take a view on the strategy-related and financial frameworks within which the sewer system management is to be carried out. These frameworks are often derived from the council programme in which the mayor and aldermen after the council elections outlined the overall municipal policy, as in for example, the sewer system tax may not increase by more than € 10 in the next 5 years, and if this results in a shortage of funds, the improvement of the system's performance has a higher priority than the improvement of the of the gravity sewer system's condition.

What exactly the task of managing a sewer system entails during the planning period of a Municipal Sewer System Plan, depends to a large extent on the local situation. The local situation is described by the following.
- The requirements defined for the performance of the sewer system and for the condition of the objects in the sewer system (quality requirements).
- The actual performance of the system and the current condition of the objects.

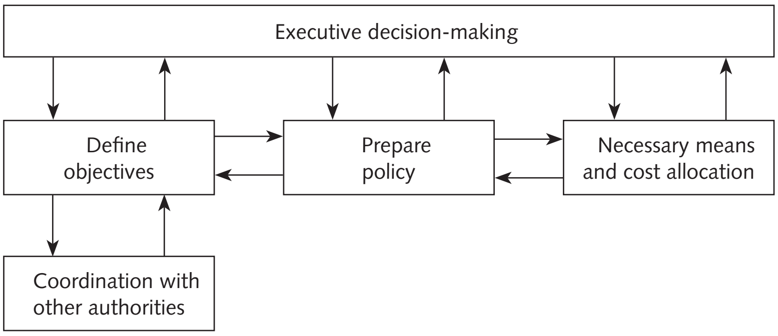
To define the quality requirements, a system of objectives, functional requirements and performance criteria as described in section 4.2 is used.
The local council sets the policy, but it is the policy official within the municipal organisation who actually prepares the sewer system policy.

Policy activities
Once the strategy has been approved by a council resolution, the mayor and aldermen become responsible for implementing the strategy as defined, and reporting back to the local council, who remain effectively in charge.

The civil service is responsible for detailing and implementing the strategy. Once a strategy has been approved, it cannot simply be converted into action plans for investigation and measures. The first thing to be investigated will be what the available options are within the framework set by the local council. A policy outlines the plan of action that will be used to implement the strategic objectives. Things to be taken into account during this process include the following.
- Other task definitions within the municipality.
- The availability of financial and human resources.
- Integration in the wastewater system.

In practice this will result in different policies. Some of these policies may not fully comply with the previously defined basis. This can mean that the basis may need to be adjusted, in which case feedback to the mayor and aldermen of the local council will be required. Figure 7.4 shows a diagram of these procedures.

Figure 7.4 Relationships between strategy and policy activities (source: NPR 3220)



Here is a real-world example of a situation in which feedback to the local council is required:
It has been found that 10% of the private properties suffer from problems because the groundwater table is consistently too high. The municipality is responsible and will have to take appropriate action. If sufficient financial resources are made available, the problems can be remedied within 5 years. However, this means that the sewer tax will have to be increased by 10% (strategy 1).
As a basis of the Municipal Sewer System Plan, the local council has stipulated that the sewer tax may not increase by more than 5%. The result of this is that the problems will take 10 years to solve (strategy 2).
Not carrying out half the sewer replacements for the next 5 years will create the financial room to nevertheless remedy the groundwater problem within the next 5 years (strategy 3).
And here is an example of a situation in which no feedback is required:
In order to gain insight into the condition of the gravity sewer system each sewer must on average be inspected once every 10 years by means of a crawler-mounted CCTV camera.
The long-term budget includes the necessary funding.

ASSIGNMENT
Look up the website of your home town and see what you can find about the involvement of the local council regarding the subject of sewer system management. When was the last time the local council approved a municipal Sewer System Plan? Can you find the main policy frameworks? Do they contain anything about preventing groundwater problems?

Only when the different policies for the basic activities have been filled in, can operational programmes be prepared.

7.3 Operational activities

In the day-to-day running of sewer system management it is important that the different activities be carried out in a coordinated fashion. This is why work plans are drawn up, and work schedules prepared. The important characteristics of sewer system management include its plan-based and cyclical nature. See figure 7.5.

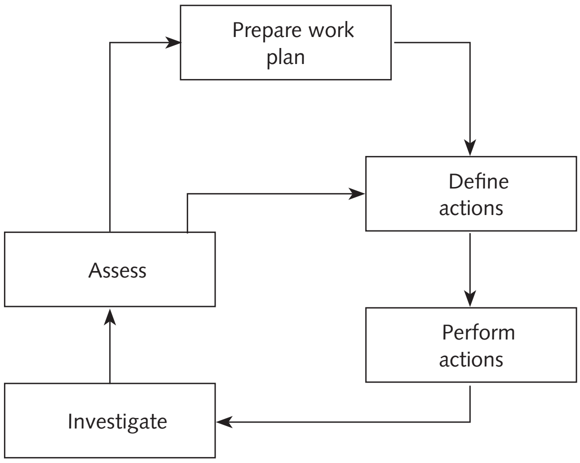


Figure 7.5 Relationships between work plan and operational management (source: NPR 3220).

Operational management focuses on four basic activities:

- Investigation: collect, order, and process data in order to obtain information about the performance of the outside sewer system and the condition of the objects it includes.
- Assessment: determine the difference between the existing situation and the required situation, and assess any difference that is found. The required condition is defined in the form of objectives, functional requirements, and performance criteria;
- Defining measures: planning where end when which measures need to be implemented;
- Implementing measures: carrying out the plans.

7.4 System and object management

A sewer system may be subject to requirements regarding both the performance of the sewers as a system and the condition of the physical objects making up the system.
Operational management will also need to focus on both the system and its objects. Basic activities are system-focused if their aim is to make changes to the original performance of the system, for example by altering the dimensions of components within the system.

Most of the day-to-day basic activities are object-focused, with investigation and assessment aimed primarily at changing the condition of a system's objects, for example by replacing sewer pipes without changing their diameter. If the pipes of a sewer are no longer strong enough and in danger of collapse, the sewer must be replaced. The result will be a modified structural condition, but if the dimensions of the sewer do not change, the change does not affect the original performance of the system as a whole.

Maintaining the required discharge capacity is a part of system management. One of the ways of doing so is to clean sewers and manholes on a regular basis. This changes the sewer's drainage condition, but leaves the structural condition of the sewers and manholes unchanged, of course.

ASSIGNMENT

In order to gain insight into the condition of sewers and manholes, inspections are carried out using a crawler CCTV camera. To make sure the structural details can be observed, the sewers and manholes must first be cleaned using high-pressure equipment. Sewers are inspected on average once every 10 years. Sewer are cleaned on average once every 7 years. The costs per kilometre of sewer are approximately equal for cleaning and inspection. Draw up a cleaning and inspection work schedule for the given situation.

ASSIGNMENT

Explain why system management and object management cannot be considered separately.

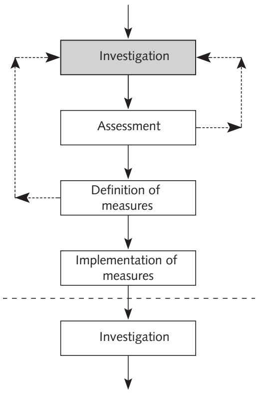
Table 7.1 shows the relationships between system and object measures in more detail.

Table 7.1 System and object measures

Activity	Object condition effect	System performance effect
Maintenance	Leave unchanged	Restore original performance
Repair	Minor condition change	Restore original performance
Renovation	Major condition change (as newly built)	Restore original performance
Replace	Remove existing object, install new object	Restore original performance
Improve	Not applicable	Restore original performance

7.5 Operational management

7.5.1 Investigation



Investigation is the first of the four basic activities in sewer system management. The purpose of investigation is to gather information about the operational status of the sewer system and about the current condition of the objects within the system.
Investigation comprises the collection, indexing, and processing of data so that information can be deducted about the performance of the outside sewer system. Investigation includes the following activities:

- Survey
- Measurements
- Calculation
- Inspection
- Enforcement (checks on permits and regulations).

Effective management requires knowledge about the following.

- The way the sewer system works. This allows the effects of management measures to be estimated in advance.
- The condition of the sewer system and the conditions in which it operates.
- The measures required to make the system performance meet the defined requirements.

As a prerequisite, sufficient financial and human resources must be available to collect and process all the necessary information.

ASSIGNMENT
Explain what can happen if the information about the condition of sewers and manholes is no longer up to date.

7.5.1.1 Investigation purpose

Investigation is not a purpose in itself, but it results from a need to have information. Information is deducted from collected data by ordering and analysing the data. If the collection of data is to be effective, the investigation must have a clear purpose. Each investigation purpose demands its own level of data quality and quantity.
Investigation can be aimed at the condition and performance of objects, and on the performance of the system.

Investigation can serve either general or specific investigation purposes.

- General investigation purposes are related to the preparation of strategic (long-term) or operational (short-term) planning. Example: As part of a road reconstruction it is being considered to replace the underlying sewer system, which is 50 years old. It is therefore necessary to know the condition of sewers and manholes in detail. Investigation method: visual inspection with a using a CCTV camera inside the sewers. Prior to the inspection the sewers must be high-pressure cleaned.

- Specific investigation purposes can be aimed at:
  - Taking away any uncertainties that may occur in the event of complaints and defects, e.g. complaints about smells.
  - The choice of measures. Example: as a result of corrosion of concrete pipes a decision has been made to replace the sewers. The work will be undertaken in combination with a road construction planned in 5 years time. The investigation query is whether the sewers are strong enough to last that period. The investigation method will consist of drilling out cores and testing these to assess the structural integrity of the pipes.
  - The inspection upon completion of construction work, during which data concerning the condition of newly constructed objects are collected.
  - Checking whether permits and regulations are being observed.

7.5.1.2 Data and information

Information is deducted from collected data by ordering and analysing the data. Effective management requires that certain procedures be defined to regulate the way in which the collection, recording, selection, processing, and analysis of data takes place.

The nature, quality, and quantity of the data to be collected are determined by the purpose a management authority has in mind. This involves the following quality aspects.

- Source
- Accuracy
- Completeness
- Consistency
- Reliability
- Mutation frequency

In theory these quality aspects appear to be simple, but unfortunately they tend to be a lot less straightforward in practice.
Collecting more data than required leads to information inflation.
The collected data are recorded in a computerised sewer management system.

7.5.1.3 Gathering data

A survey involves collecting data about the following items.

- Designs and revisions of sewer system objects
- Local conditions
- Object conditions
- Sewer system performance

The collected survey data can be either fixed or variable.
Fixed data refer to the general structure and the layout of the sewer system.
Variable data change in time, e.g. the condition of a certain stretch of sewer.

You collect the required data by venturing out in the field or by searching through existing information such as databases.

7.5.1.4 Inspection

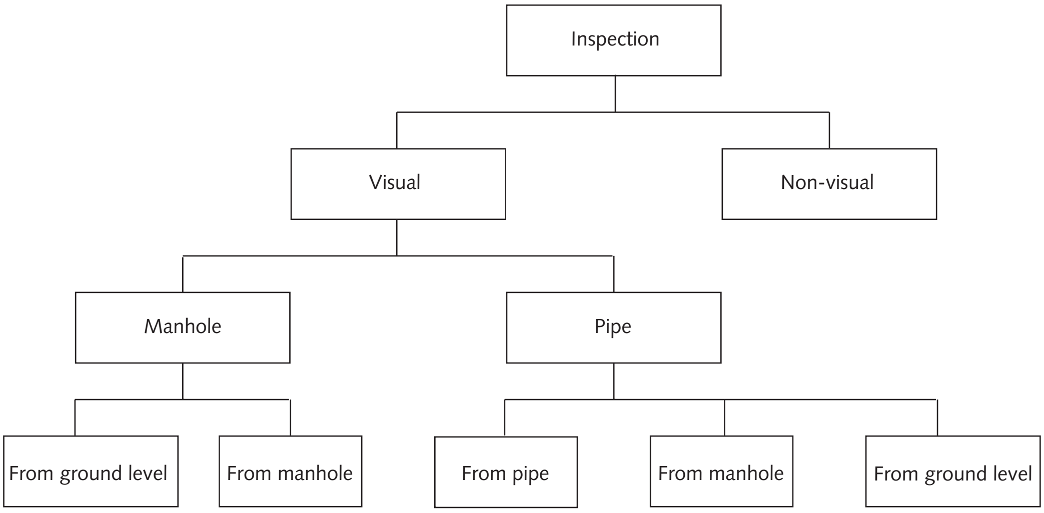
The purpose of inspection is to collect data about the condition of the various objects making up the sewer system. The condition observed during the inspection is then described systematically by the inspector.

The following types of inspection can be distinguished:

- Inspection for a strategic (long-term) or operational (short-term) planning.
- Inspection to investigate complaints and defects.
- Inspection to determine measures.
- Completion inspection.
- Inspection in connection with permits and regulations.

Inspection methods can be either visual or non-visual. Non-visual inspection methods usually involve measurements.
Figure 7.6 shows a list of inspection methods.

Figure 7.6 List of inspection methods (source: RIONED Foundation)



The best inspection method is the method best suited to the purpose of the investigations. Table 7.2 shows the relationship between the various investigation purposes and the appropriate inspection methods.

Table 7.2 Relationship between investigation purposes and inspection methods (Source: RIONED Foundation)

Inspection method	Investigation purpose					
	General		Specific			
	Strategic planning	Operational planning	Taking away uncertainties	Determining measures	Completion inspection	Permits and regulations
Manhole						
Visual from manhole	-	-	+	+	**	+
Non-visual	-	+	++	++	++	++
Sewer pipe						
Visual from manhole	++	+	-	-	-	-
Visual from sewer pipe	+	++	+	+	**	+
Non-visual	-	+	++	++	**	++

Legend:

** Closely related, application normative
++ Closely related
\+ Related
\- Unrelated

ASSIGNMENT

What is the best inspection method for:

A Completion inspection of newly constructed sewers.

B Determining whether an existing sewer should be replaced as part of a road reconstruction.

The visual inspection methods are described below.

- Visual inspection of the sewer from inside the manhole:
  - Visual inspection without technical aids: the condition is observed using sewer mirrors or by direct observation after entering the manhole.
  - Manhole photo or video inspection: the condition is observed by means of optical aids without entering the manhole. The imaging equipment is lowered and held in front of the pipe opening in the manhole.
- Visual inspection of the sewer from within the sewer:

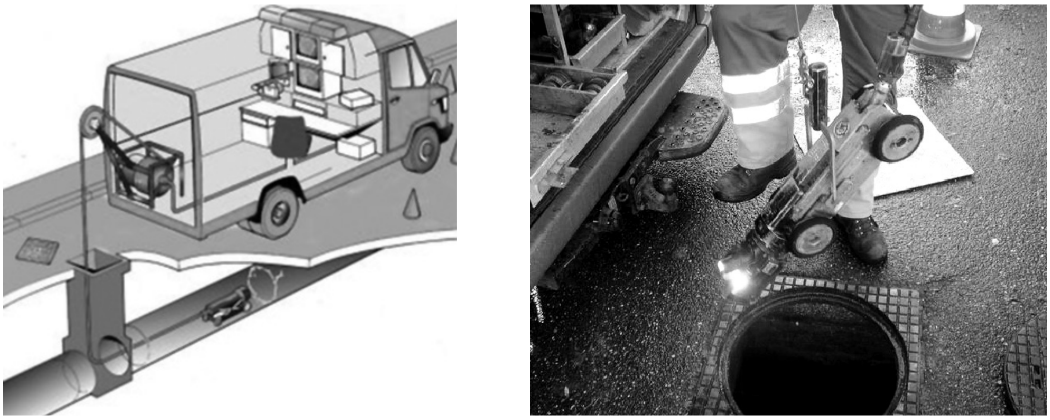


Figure 7.7 Visual inspection of a sewer using a mobile CCTV camera

- Visual inspection using a CCTV camera moving through the sewer. The sewer must first be cleaned.
  - Personal inspection: if the pipe diameter is sufficient, the inspection can be carried out by a person moving through the sewer. The sewer must first be cleaned.
  - Visual inspection of the manhole from within the manhole:
- Optionally using optical aids and from ground level without entering the manhole.
  - Manhole photo or video inspection: the condition is recorded using photographic or video equipment without entering the manhole. The imaging equipment is lowered and held inside the manhole chamber.
  - CCTV camera inspection from the bottom of the manhole: the condition is recorded using a mobile CCTV camera.

All methods that require one or more persons to enter the sewer are subject to a whole range of safety precautions. This is because every working sewer is a hazardous environment in itself. Most sewers are also located below roads, which do not make safe working environments either. The health and safety of sewer workers is ensured by (statutory) regulations that must be observed.

ASSIGNMENT
On the website of the RIONED Foundation, view the movie clip of a CCTV camera inspection: http://www.riool.info

Non-visual inspection methods

In non-visual methods observations are made without using optical aids such as cameras. These methods are intended mainly to recording the condition of an object.

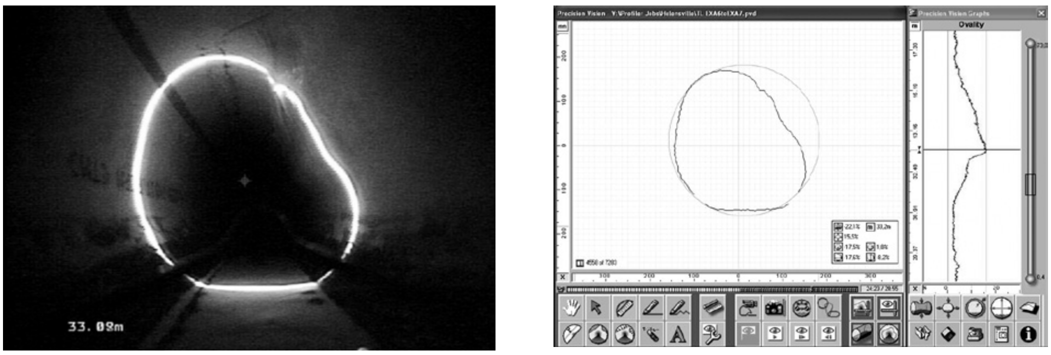


Figure 7.8 Example of measuring pipe deformation. Source: www.cleanflowsys-tems.com

ASSIGNMENT
On the website of Cleanflow Systems, take a look at the different techniques available for measuring sewers.

ASSIGNMENT
In Guideline module C2400 look for the list of visual and non-visual inspection methods. Find the non-visual method that will enable you to assess how much the wall of a concrete pipe has been chemically eroded.

Visual inspection is a method that has seen a lot of development in the past 25 years. The principle is that images must be available of every sewer and every manhole within the Dutch gravity sewer system, together with a standardised condition record.
The observations of all types of visual inspection (the condition aspects) are recorded using a uniform classification system. This classification system is defined in the standard European NEN-EN 13508, part 2. For the Dutch situation NEN 3399 is augmented by 'Classification system for visual inspection of objects' (*Classificatiesysteem bij visuele inspectie van objecten*). Both standards must be used together. Therefore, the management authority must prescribe both standards for carrying out visual inspections if a good enough inspection product is to be obtained.

The classification system is in fact a standardised list of images of condition issues that can be recognised in sewers and manholes. For each condition issue the system has a main code. The condition recording system for sewers uses a total of 28 main codes.

Here are some examples of main codes for condition issues in sewers.
- BAG: intruding connection
- BBD: ingress of soil
- BBF: infiltration
- BDD: water level

Figure 7.9 Examples of main codes BAG, BBD, and BBF (from left to right)

In the Dutch situation the following applies.
- A main code consists of three letters.
- A further specification of the condition issue is indicated by up to two additional letters.
- The detail description of a condition issue is indicated by a class number (1 to 5).

Class 1 means that the condition issue was observed not at all or only to a very limited extent. Class 5 means that the condition issue was observed to its maximum extent. The maximum is defined in NEN 3399.

For the photos in figure 7.9 above the full code is (from left to right):
- BAG class 5: connection intruding over a length in excess of 25% of the pipeline height.
- BBD A class 5: ingress of soil in the form of sand, with the pipe diameter being obstructed for more than 25%.
- BBF class 5: groundwater gushing into the pipe.

Figure 7.10 illustrates the principle of visual inspection in accordance with NEN 3399.

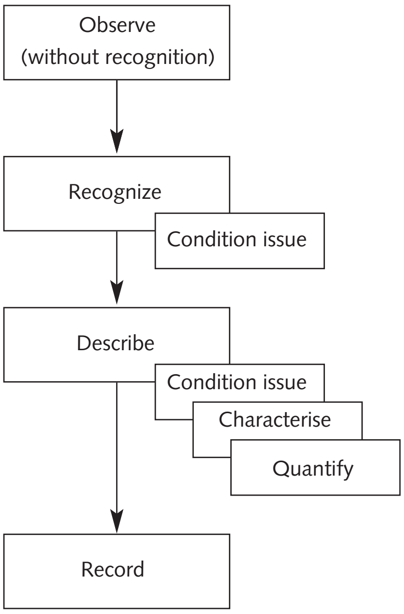


Figure 7.10 The principle of visual inspection in accordance with NEN 3399 (source: RIONED Foundation)

NEN 3399 uses a system of classes for recording the observations. These classes have nothing to do with the severity of a condition. After all, indicating whether something is good or bad is fact an assessment. No assessment takes place during an inspection. Assessment is the second basic activity.

Figure 7.11 below reproduces a part of the coding system.
The full list can be downloaded from the website of the RIONED Foundation.

Figure 7.11 Selection of the coding system in accordance with NEN 3399 (source: RIONED Foundation)

Table: codes for condition issues during visual inspection of a sewer from inside the sewer in accordance with NEN 3399

Main code		Characterisation 1		Characterisation 2		Quantification 1.2	Class	Class description
Code	**Description**	**Code**	**Description**	**Code**	**Description**	**Description**		
BAA	Deformation	A	Vertical			--->	1	Not observed
	Attention: flexible	B	Horizontal			--->	2	Deformation <= 5% of the diameter
	pipes only					--->	3	5% < deformation <= 10% of the diameter
						--->	4	10% < deformation <= 15% of the diameter
						--->	5	Deformation > 15% of the diameter
BAB	Fissure		--->	A	Axial		1	Not observed
			--->	B	Circumferential		2	Surface crack – crack in surface only
			--->	C	Complex		4	Crack – visible crack lines on the pipe wall, pieces still in their place
			--->	D	Helical		5	Fracture – visibly open cracks in the pipe wall, pieces still in their place
BAC	Break / collapse		--->			length of the	1	Not Observed
			--->			crack in mm if	2	Break – parts of the pipe visibly displaced, but not missing
			--->			> 1,000 mm	4	Missing – parts of the wall are missing
			--->				5	Collapse – complete loss of structural integrity
BAD	Defective brickwork or masonry		--->	A	The next layer of bricks or brickwork is visible		1	Not observed
			--->	B	Nothing is visible		2	Displaced
			--->				3	Missing
			--->				4	Dropped invert
			--->			in mm -->	5	Collapse
BAE	Missing mortar					--->	1	Not observed
						--->	2	Mortar depth <= 10mm
						--->	3	10 mm < mortar depth <= 20 mm
						--->	4	20 mm < mortar depth <= 40 mm
						--->	5	Mortar depth > 40 mm
BAF	Surface damage		--->	A	Mechanical damage		1	Not observed
			--->	B	Chemical erosion –		2	Spalling, visible aggregate, erosion material on the surface
					General			
			--->	C	Biochemical erosion		3	Aggregate projecting from the surface or visible reinforcement
					above water level			
			--->	D	Chemical erosion below		4	Missing aggregate or reinforcement projecting from the surface
					water level			
			--->	E	Cause unclear		5	Missing wall of corroded reinforcement
BAG	Intruding connection (record BCA also)					--->	1	Intrusion length < 10% of pipeline height
						--->	3	10% < intrusion length < 25% of the pipeline height
						--->	5	Intrusion length > 25% of the pipeline height
BAH	Defective connection		--->				1	Not observed

Classification of condition issues requires special skills of the inspector, who is trained for the job by the RIONED Foundation. In addition visual inspection for ISO certified inspection companies is subject to a national assessment code (*beoordelingsrichtlijn, BRL*).

7.5.1.5 Measuring

Measuring is an investigation method aimed at collecting data on:

- the condition of objects;
- the performance of the sewer system.

> Example of the collection of sewer system performance data.
> Required: knowledge whether the discharge capacity of the rainwater sewer system meets the design criteria.
> Method: flow rate measurement in the sewer during precipitation, and simultaneous measurement of the precipitation.

Measuring requires a systematic approach, with measurements being taken according to a predefined plan taking into account the intended purpose, after which the data are processed into information ready for analysis.
Measuring targets must be defined so we know exactly what must be measured, which readings will be required, and what the minimum required number of data will be.
Measuring targets can be aimed at the following.

- Quantifying the condition and the performance of objects, using readings to see whether previously set performance criteria are met.
- Checking the effectiveness of an implemented measure.
- Validating or calibrating theoretical models.

> Here are some examples of measuring targets:
> Gaining insight into the vertical disposition of the sewer. Measuring method: gradient measurements during CCTV camera inspection, or measuring the pipe's invert level relative to the national standard level (*NAP*).
> Gaining insight into the effectiveness of disconnecting rainwater drains from a foul water sewer system. Measuring method: registration and analysis of sewer pumping station operating hours and precipitation data.

The collection of data on the performance of sewer systems is a major theme these days due in part to the changing climate.

The performance of a sewer system can be looked at from two different angles:

- Monitoring the performance on a continuous basis
- Specific investigation into the performance (understanding though focused measurement).

This is shown in figure 7.12.

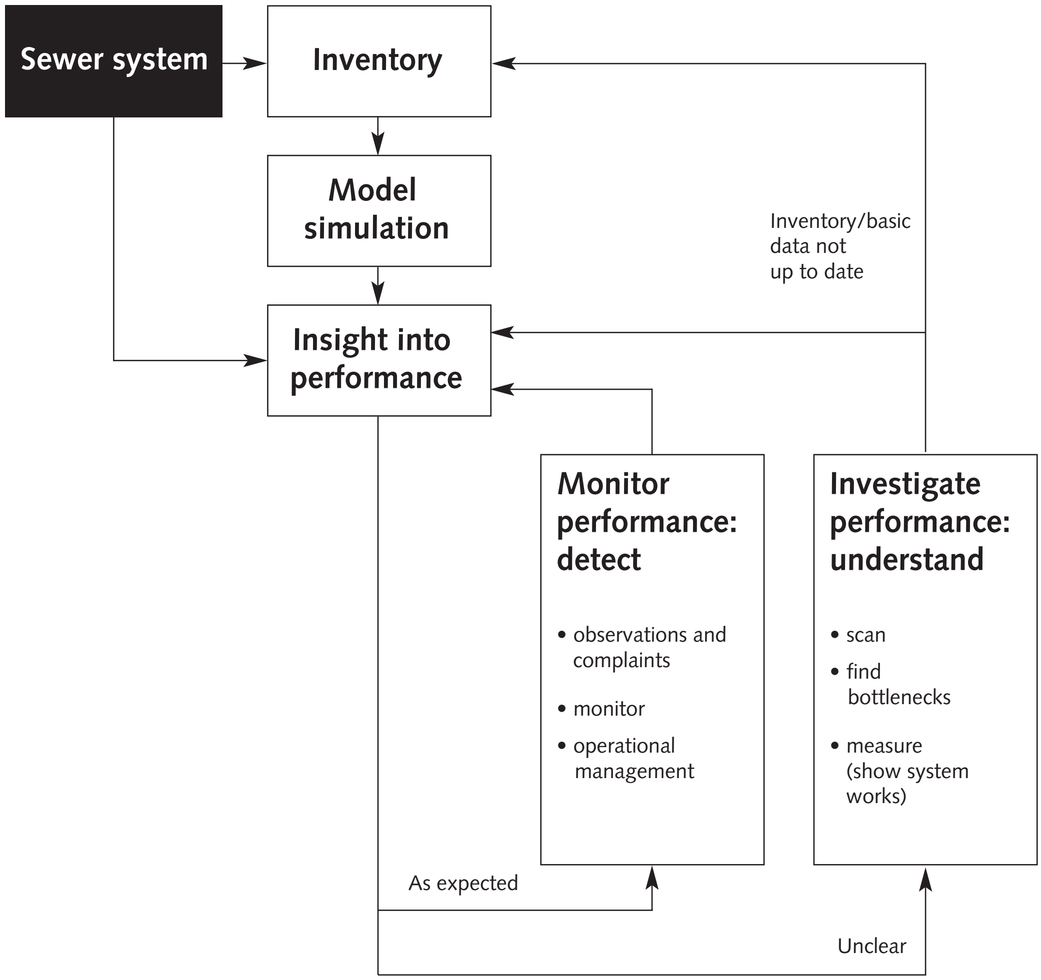


Figure 7.12 Measuring methods when collecting data on the performance of sewer systems (source: RIONED Foundation, Urban Drainage Guideline module C2300)

Performing measurements on sewer systems is a costly and time-consuming business. Calculations can be carried out relatively quickly and cheaply. Calculations are not a full alternative to measurements, but can yield relevant data, depending on the purpose of the investigation.

7.5.1.6 Calculation

Calculation is an investigation activity in which calculations (often involving the use of computers) are used to estimate the performance of a sewer system (the system behaviour), the performance of objects in the sewer system, or the remaining service life of the sewer system.

To enable the performance of a sewer system to be assessed, computer simulations must be carried out. The method is described in module C2100 of the Urban Drainage Guideline. The subject of calculations was discussed in chapter 5.

A useful assessment of the quality of objects in a sewer system takes more than just visual inspection. Non-visual investigation, for example the analysis of core samples taken from a pipe segment, can provide additional information to complement e.g. strength calculations. In this type of calculation a structural calculation is used to determine the safety margin to prevent collapse of the structure. Information about this type of calculation can be found in the CUR/VB publication no. 122 and NEN 3650.

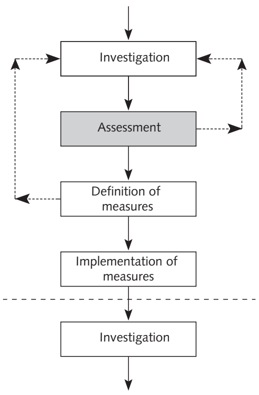
A completely different type of calculation is to do with determining the priority of replacement measures. Like any technical structure, sewers will degrade as a result of mechanical (wear and tear, damage) and chemical (corrosion, loss of stability) processes. Most of the software for sewer system management include behaviour models that can be used to estimate the remaining service life. Using these models, extrapolation of inspection results, sometimes complemented by a multiple criteria analysis with weighting factors, can lead to a prognosis of the remaining service life. However, in view of the lack of statistical basis for the information, the calculation results need to be considered with some caution.

7.5.1.7 Permit checks

As manager of the local sewer system outside buildings, the municipality acts as the relevant authority, but is itself also subject to legislation. Chapter 3 discussed the bye-laws and permits that directly affect the objects (condition or performance) or the performance of the sewer system. To make sure these resolutions and the permit conditions are observed, work needs to carried out in the form of checks.

These checks can include:

- Finding incorrect connections and illegal discharges
- Administrative checks
- Sampling and measuring



7.5.2 Assessment

Assessment is a basic activity in the management process. It is aimed both at evaluating the condition and the performance of sewer system objects and at evaluating the performance of the sewer system as a whole. Useful tools in this process are NEN 3398, ‘Investigation and condition assessment of objects’ (*Onderzoek en toestandsbeoordeling van objecten*), and RIONED Foundation Guideline module C2400: inspection and assessment.
This section will look in particular at the assessment of the condition of sewer system objects.

7.5.2.1 Assessment process outline

The purpose of assessment is to determine whether any measures are required, and if so, which measures. Assessment focuses in particular on answering the following questions:

- When should the measures be taken? (priority)
- What is the nature of the measures? (replacement, repair, renovation, maintenance)

The nature of a measure depends on the nature and the severity of the observed anomalies, i.e. deviations from the required situation. The priority depends mainly on the risk involved if a measure is not taken in time.
The assessment of sewer system objects takes place within the context of the sewer system, taking only into account the conditions that affect the sewer system. Any coordination within the context of the municipal territory does not take place until after the priority and the nature of the measures have been determined.

The assessment process is shown in figure 7.13 and will be discussed below.

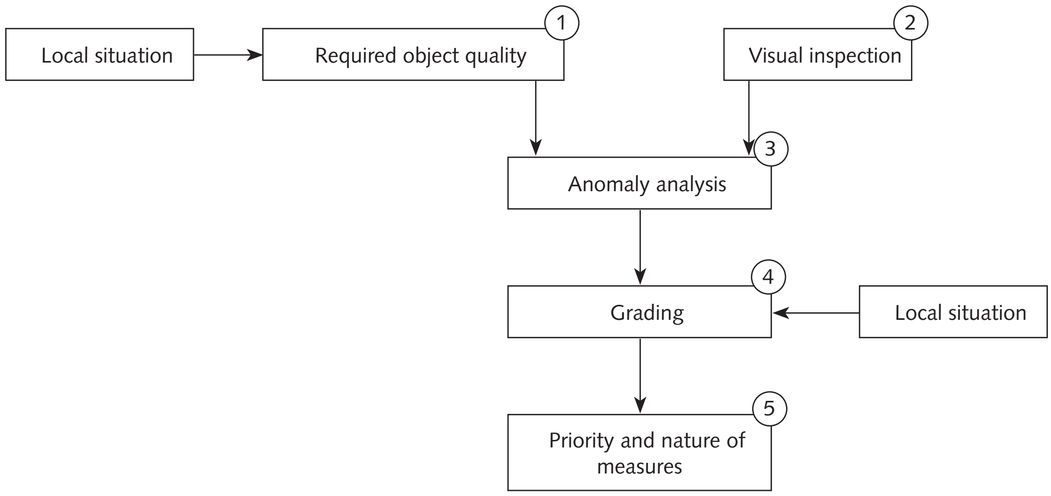


Figure 7.13 Assessment process (source: RIONED Foundation)

1. Determine the required quality of the objects, taking into account the local situation which is based on the objectives and functional requirements, as defined in the Municipal Sewer System Plan.
2. Collect data by carrying out a (visual) inspection
3. Perform an anomaly analysis to see whether the actual situation a observed differs from the required performance or the required condition.
4. Assess the observed differences as found in the anomaly analysis, taking care to include the local conditions as well as the nature, cause, severity, and extent of the shortcomings.
5. Determine the urgency and nature of the measures, as determined by the risk involved if action is not taken in time. The nature of the measure depends on the nature, severity, and extent of the shortcoming.

Once the measures have been defined and the term for action set, the measures can be prepared and carried out.

7.5.2.2 Activities in the assessment process

The required quality
A municipal sewer system plan must provide a specific and measurable description of the required quality level of the object condition. The quality level is specified in criteria, which must always be defined in advance.
When defining criteria, the local conditions must be taken into account, as must the nature, cause, severity, and extent of the damage to be recorded.

The required condition of objects is specified using the coding system as defined by NEN 3399.
For various reasons, some of which are simply practical, two types of criteria are distinguished:
- Warning criteria: the current condition is open to discussion, and further investigation is required.
- Action criteria: the current condition does not meet the required quality. Action needs to be taken. Action criteria have nothing to say about the time within which the action must betaken (the urgency).

The required condition is the basic quality that is regarded as acceptable.
A municipal sewer system plan must include a list of the required object quality or action criteria.
This is what is known as the basic quality of the objects.

The NEN 3398 standard includes a table that can served as a basis for the list. The principle of the basic quality is that is must be demonstrably based on the local conditions (section 11.3.2 in NEN 3398). Table 7.3 below lists the criteria for a specific situation.

Table 7.3 Example of a table with warning and action criteria

Main Code	Condition issue	Warning criterion	Action criterion
BAA	Deformation	3-4	5
BAB	Fissure	4	5
BAC	Break/collapse	–	2-5
BAD	Defective brickwork or masonry	3	5
BAE	Missing mortar	3	4-5
BAF	Surface damage	3	4-5
BAG	Intruding connection	3	5
BAH	Defective connection	2-3	4-5
BAI A	Intruding sealing material – sealing ring	2	3-5
BAI Z	Intruding sealing material – other	3-5	5
BAJ A	Displaced joint – axial	3-5	5
BAJ B	Displaced joint – radial	2-3	4-5
BAJ C	Displaced joint – angular	5	–
BAK	Defective lining	3	4-5
BAL	Defective repair	2	3-5
BAM	Weld failure	2	3-5
BAN	Porous pipe	5	–
BAO	Soil visible through defect	–	5
BAP	Void visible through defect	–	5
BBA	Roots	2-3	4-5
BBB	Attached deposits	2-3	4-5
BBC	Settled deposits	2-3	4-5
BBD	Ingress of soil	≥2	3-5
BBE	Other obstacles	2-3	4-5
BBF	Infiltration	3	4-5
BBG	Exfiltration	–	5
BBH	Vermin	–	5
BDD	Water level	2-3	4-5

As an example, the ‘intruding connection’ condition (BAG) as seen in figure 7.9 has been worked out in further detail.
Purpose: to ensure the transport of urban wastewater
Functional requirement: the discharge must be safeguarded
Performance criterion: the basic quality for the ‘intruding connection’ condition must be class 1 or 3.
The basic quality for condition BAG class 1-3 is shown in figure 7.14.
This means that the action criterion in this municipality is class 5.

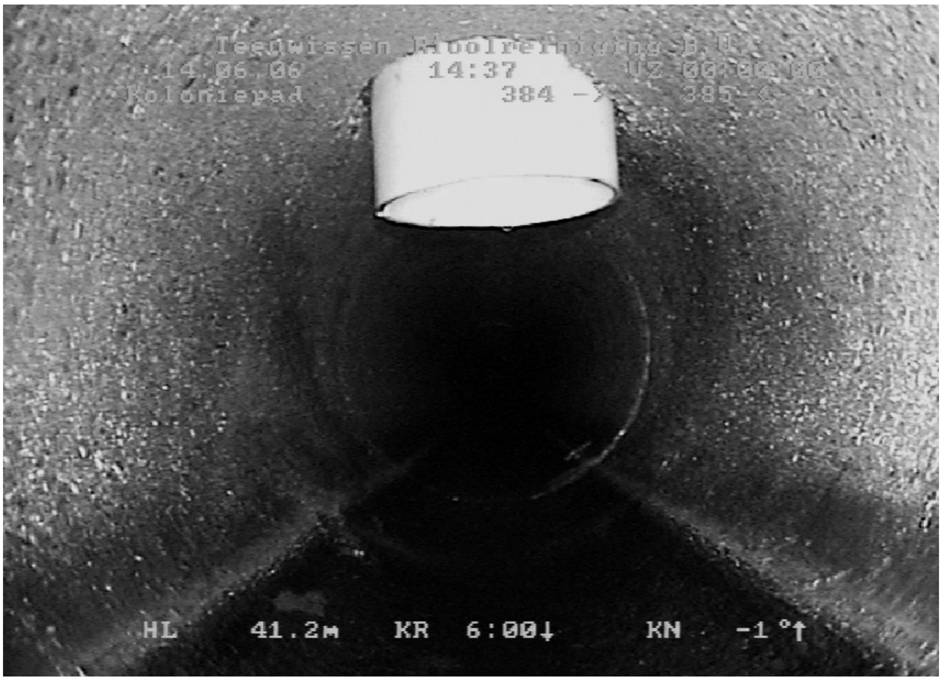


Figure 7.14 Basic quality for condition BAG: class 1-3 (Source: RIONED Foundation)

ASSIGNMENT
How far can a connection intrude from the pipe wall if the basic quality is to be met?
Use figure 7.9 to find the answer.

Recording the existing situation
The existing condition of a sewer is recorded by means of an inspection method, the nature of which depends on the purpose of the inspection.
Example (continues the condition BAG example).
As part of a road reconstruction programme the condition of the existing gravity sewer system has been recorded using a crawler-mounted CCTV camera. The picture below was taken during the inspection. The picture has been marked with the code as defined by the inspection standard NEN 3399 for the 'intruding connection' condition.

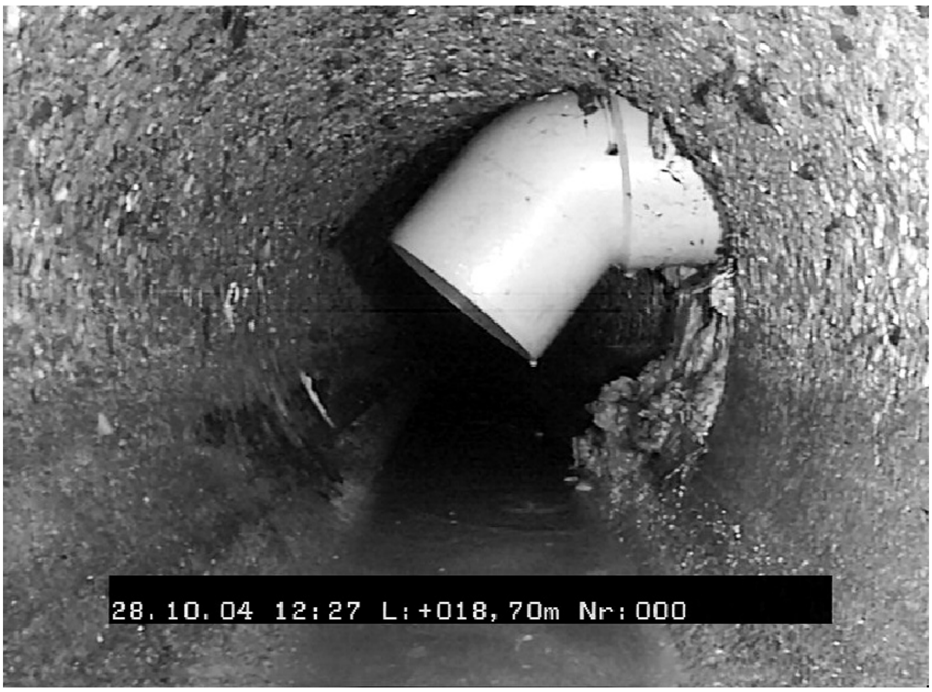


Figure 7.15 BAG class 5 (Source: Van der Velden sewer management)

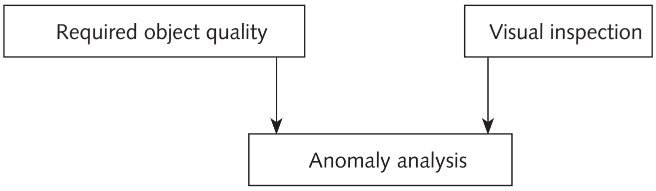


Figure 7.16 The anomaly analysis

Both the basic quality (the required condition) and the results of the visual inspection consist of codes as defined by NEN 3399. As the inspection data are supplied in a digital file using a standard format, any discrepancies can be detected automatically. This means that the anomaly analysis is a simple process.
The anomaly analysis provides insight about locations in the sewer system where the condition does not meet the required basic quality, i.e. where an action criterion applies.

ASSIGNMENT
Using the two photographs on the previous page, perform the anomaly analysis. Use the information given in the text.

Assignment solution: Basic quality: BAG class 1 or 3. Observed condition: BAG class 5. Conclusion: With regard to the condition issue 'protruding inlet' the condition does not meet the basic quality: the observed BAG class 5 is an action criterion according to figure 7.14.

Assessment
After carrying out the anomaly analysis, the actual assessment starts, with all the available data being carefully considered in order to enable the following to be done.
- To indicate a period within which a measure must be completed (priority level allocation);
- To make a provisional choice regarding the nature of the measure.

During the assessment the following questions must be answered:
- How much is the difference between the required condition and the observed condition?
- What is the nature of the damage?
- Is the damage single or multiple?
- What caused the damage?
- What are the consequences of the damage?
- What are the risks if the damage is not remedied in time?

The nature of a measure (repair or replacement, for example) depends on the nature and the extent of the damage and the extent to which the condition deviates from the required quality.
The priority of a measure is determined by the resulting risks if a measure is not implemented at all, or not implemented in time.

ASSIGNMENT
Based on the above anomaly analysis, assess the condition you observe in the picture (figure 7.15). Are there any data missing for a well-funded assessment?

Procedure:
Result of the protruding inlet: floating debris may get caught behind the protruding inlet, with the risk of blockage, severely reducing the discharge capacity of the sewer. This situation will have to be remedied with priority.
Nature of the measure: cut away the protruding inlet using a robot cutter.

Service life of sewer system objects
Structural objects are subject to ageing processes as a result of mechanical or chemical processes. An object's service life may also be reduced by design errors, an incorrect choice of materials, and construction errors. To what extent each of these factors play a role depends heavily on the local conditions and the nature of the materials involved.

Local conditions that affect service life include the following.
- Nature of the wastewater (urban wastewater or rainwater).
- Geometry of the object (location and depth).
- Local infrastructure (both above ground and underground).
- Geohydrological situation (groundwater table and soil structure).
- Useful loads acting on the object.

The term service life can be defined in a number of different ways. i.e. the technical, the economical, the absolute and the public service life.

We will restrict ourselves to the technical service life.

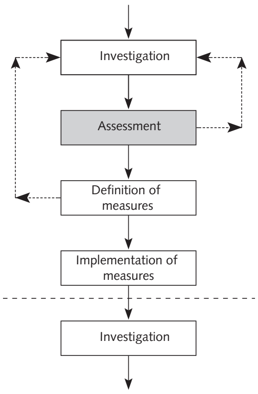
ASSIGNMENT
Find out what the effect of these conditions is.

Forecasting the remaining technical service life
Ask yourself the following. When is a car technically written off? Is it the moment it finally fails its MOT, or is it when the garage costs for maintenance and repairs keep mounting?

ASSIGNMENT
When can you say that the technical service life of a sewer has ended? Is it when the sewer collapses and can no longer carry away the wastewater, or is it at the moment an action criterion condition has been observed?

For a sewer, the action criterion is when it fails its MOT. After all, a municipality has decided for its own local situation, based on a number of reasons, what constitutes an undesirable situation. Safety inspection systems like the MOT are subject to national standards, but there is no such thing for sewer system objects, because the local conditions affect the criteria.

It would be ideal if we could predict the remaining technical service life to the day. Unfortunately we can't. If we could, it would mean that we would be able to accurately mimic the various changes that occur over time in a behavioural model. We haven't reached that stage yet.
The computerised management systems currently on the market do feature simple models that allow a priority action list to be compiled on the basis of the observations from sewer inspections.



7.5.3 Management measures
This section discusses management measures aimed at improving the condition of the objects in a sewer system. The discussion of the measures follows the list in table 7.5 below.
Depending on the effects on an object's condition and on the system's performance, the following main groups of measures are distinguished: maintenance, repair, renovation, and replacement. See the table below.

Table 7.4 Object-focused management measure categories (source: NEN 3398)

Category	Effect on object condition	Effect on system performance
Maintenance	Maintain unchanged	Restore original performance
Repair	Limited condition change	Restore original performance
Renovation	Radical condition change (like new structure)	Restore original performance
Replacement	Removal of existing object, installation of new object	Restore original performance

Maintenance involves the removal of undesired obstacles (both fixed and loose) and deposits.
Repair involves restoring the object, usually locally, for the purpose of extending its service life.

Table 7.5 Relationship between management measures and condition observations for sewers in accordance with NEN 3399 (source: Urban Drainage Guideline module C3000)

NEN 3399:2004 (sewers)

Level of effect on condition description
  = none
0 = slight
\+ = medium
++ = high

x = relevant to application

* = dig method

NEN 3399:2004 (sewers)	1.1 High-pressure cleaning	1.2 Cutting	1.3 High-pressure cleaning with foam pig	1.4 Sewage suction	1.5 Blasting	2.1 Lining with cured-in-place pipes	2.2 Local slip lining	2.3 Local grout injection	2.4 Internal repair ring	2.5 Injection from sewer pipe/manhole	2.6 Injection from ground level	2.7 Injection in concrete	2.8 Robot techniques	2.9 Manual repair	2.10 Inlet repair *	2.11 Concrete jacket *	2.12 External repair ring *	2.13 Local (pipe) replacement *	3.1 Coatings (method-specific)	3.2 Helically-wound pipe lining	3.3 Lining with pipe segments	3.4 Cured-in-place lining	3.5 Rigid pipe slip lining	3.6 Flexible pipe slip lining	3.7 Cement spraying	3.8 Plastic coatings	4.1 Pipe bursting	4.2 Drill out	4.3 Full replacement
	Cleaning					Repair													Renovation								Replacement		
Management measure application																													
Gravity pipes	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
Pressure and vacuum pipes			x															x	x			x	x	x	x		x		x
Connections	x								x	x			x	x	x		x	x	x							x			x
Material type code																													
BAA Deformation																		++									++	++	++
BAB Fissure						++	++		++			++	++	++		++	0	++		++	++	++	++	++	+	++	++	++	++
BAC Break/collapse						++	++						+							++	++		++	++			++	++	++
BAD Defective brickwork						++	++									+				++	++	++	++				++	++	++
BAE Missing mortar						++	++		0			+	+	++						++	++	++	++	++	++	++	++	++	++
BAF Surface damage						++	++		0			+	++	++				++		++	++	++	++	++	++	++	++	++	++
BAG Intruding connection		+											++	++	++			+									++	++	++
BAH Defective connection								+		+	+		++	++	++	++	+	++									++	++	++
BAI Intruding sealing material		++				+	++		++				+	++				++		++	++	++	++	++	+	++	++	++	++
BAJ Displaced joint						++	++		++				+			+	+	++		++	++	++	++	++	+	++	++	++	++
BAK Lining defect						++	++		+	+			++	++				++	0	++	++	++	++	++		++	++	++	++
BAL Defective repair						++	++	+	+	++		++	++	++	++		++	++		++	++	++	++	++	++	++	++	++	++
BAM Weld failure						++	++	++	++	+			++	++						++	++	++	++	++		++	++	++	++
BAN Porous pipe						++	++		+	++		++	++	++				++		++	++	++	++	++	++	++	++	++	++
BAO Soil visible through defect						++	++		++				++	++		++	++	++		++	++	++	++	++		++	++	++	++
BAP Void visible through defect						++	++		++				++	++		++	++	++		++	++	++	++	++		++	++	++	++
Performance code																													
BBA Roots		++				++	++	0	++			++	++	++	++	0	++	++		++	++	++	++	++		++	++	++	++
BBB Attached deposits	+	++	+										+	++					0								+	+	+
BBC Settled deposits	++	+	+										+	++					0										
BBD Ingress of soil	+																												
BBE Other obstacles	+	+																											
BBF Infiltration						++	++	++	++	+	+	++	+	++	++	+	++	++		++	++	++	++	++	+	++	++	++	++
BBG Exfiltration						++	++	++	++	+	+	++	+	++	++	+	++	++		++	++	++	++	++	+	++	++	++	++
BBH Vermin																													

Renovation involves the extensive repair of an object so that the end result matches the new structure.
Replacement involves the removal or complete decommissioning of an existing object followed by the installation of an object with specifications matching those of the existing object.

ASSIGNMENT
Using the Guideline module C3000, find out the meaning of the ++, +, and 0 designations in table 7.5.

7.5.3.1 Choosing a measure
The results of the condition assessment are:
- A time within which a measure must be completed.
- A provisional choice of measure: clean, repair, renovate, or replace.

Table 7.5 helps to choose the management measure. The provisional choice of a measure will be discussed in more detail when we look at measure preparations.

The final choice of measure depends on a number of factors, the most important of which are the construction costs relative to the expected technical service life.
The local conditions also greatly affect the choice of measure:
- If digging proves impossible (apart from financial considerations), only no-dig techniques can be used.
- The type of sewer. If a sewer cannot be accessed by persons, any techniques that require personal access to the sewer cannot be used.
- The feasibility of the repair technique. If remedying a specific defect can cause new defects, the repair technique is unsuitable for the purpose. When determining the final choice of measure, it is almost always necessary to carry out additional investigation work.

Additional investigation work focuses on collecting information about the soil structure, the foundation of the object, and the groundwater table.

ASSIGNMENT
Think of a situation in which the improvement of sewer system objects can easily be combined with improving the hydraulic performance of a sewer system.

One last aspect of choosing the measure is whether any measures to improve the performance of the sewer system should be taken at the same time.

In the following sections some measures will be discussed in more detail. For each type of measure two different techniques are discussed to give the reader an impression of the specific technical aspects. For more detailed information please refer to the Urban Drainage Guideline and the websites of the relevant specialist companies.

7.5.3.2 Maintenance
Maintenance is restoring the original performance of the sewer system without changing the object. The purpose of maintenance is to prevent a future lack of performance or to overcome defects or complaints. Maintenance involves the removal of obstacles from within a sewer pipe or manhole. This can be material that was carried along by the sewer flow and has settled or become attached to the wall of the pipe of manhole. The proper flow can also be obstructed by parts of the existing sewer system.

There are five different techniques:
- High-pressure cleaning
- Cutting
- High-pressure cleaning with a foam pig (in pressure pipes)
- Sewer suction
- Blasting

Of these techniques, we will discuss high-pressure cleaning and cutting.

High-pressure cleaning

This method is used to remove all loose materials from the interior of inaccessible sewers and manholes. A high-pressure hose fitted with a jet nozzle uses high-pressure water to dislodge the obstacles and flash them back to a manhole.

Figure 7.17 High-pressure jet nozzle

ASSIGNMENT
Argue why a foul water sewer would need to be cleaned more often than a storm drain sewer

A sewer suction truck then collects the debris that has collected in the manhole. This type of equipment can develop pressures high enough to severely damage the pipe wall. As a rule of thumb, sewers and manholes need to be cleaned this way once every 5 – 15 years. The frequency depends very much on the operating conditions inside the sewer system, and it has been assumed that a foul water sewer requires more intensive cleaning than a storm drain sewer.

Cutting

Cutting is a technique that is used if the sewer contains materials that are so strongly attached to the sewer structure that they cannot be removed using the normal high-pressure cleaning equipment. One example is ingrowing plant roots. It is also possible that the pipeline contains obstacles that form part of the pipe structure itself, e.g. intruding connecting pipes and sealing material (sealant or rubber ring). See the examples below.

Figure 7.18 Left photo source: Van den Akker CIS Centre photo source: municipality of Blaricum Right photo source: municipality of Blaricum

ASSIGNMENT
Argue which of the two cutting techniques works out the cheapest in practice, and which cutting technique would be suitable in each of the situations shown in the photos above.

There are two cutting techniques:

- A technique in which a rotating wheel with cutting teeth or chains is moved through the sewer. A high-pressure cleaning truck controls and powers the cutter using a minimum water pressure of 150 bar at a water consumption of 300 litre per minute.
- A cutting robot, which allows obstacles to be removed with accuracy. The robot is very suitable for removing local obstacles such as those shown in the photos, and for drilling inlets after a sewer has been relined.

7.5.3.3 Repair

Repairs are relatively minor operations aimed at extending the technical service life with at least a few years. Repair involves rectifying damages that are limited in extent and number. Depending on the nature of the damage this can be done from the outside (by digging locally) or by means of a no-dig method. In practice, no-dig techniques are normally used. The currently available repair techniques are such that local damage can be remedied for extended periods. Repairs will generally allow large-scale renovations or replacements to be postponed.
The following repair measures are distinguished:

No-dig techniques	Dig techniques
Cured-in-place liner	Connection repair
Local slip lining	Concrete jacket
Local injection grouting	External repair ring
Internal repair ring	Local replacement
Injection from pipeline or manhole	
Injection from ground level	
Injection in concrete	
Robot techniques	
Manual repair	

The choice of repair technique depends on:

- The type of damage and the interaction with the environment (pipe and soil).
- The product properties of the available techniques.

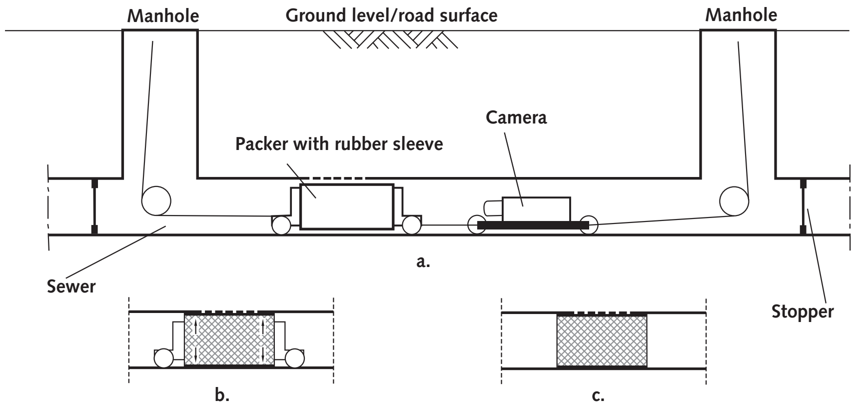
The best repair technique is the one of which the functional properties best match those of the defect in its environment. As an aid for choosing the right technique, see the tables 2.1 and 2.2 in module C 3000 of the Urban Drainage Guideline, which for each management measure list its general effect on the condition issue (the defect) that needs to be rectified.
The cured-in-place lining method (no-dig) and the local injection grouting method (dig) are discussed in more detail below.

Cured-in-place lining method (no-dig)

This technique uses a synthetic resin-impregnated liner. Two different methods exist:

- A synthetic resin-impregnated fibreglass fabric is fitted around an inflatable sleeve surrounding a hollow cylinder, known as a packer, which is winched to the desired location. The sleeve is then inflated with water or air, pressing the fabric against the existing pipeline wall, to which it becomes attached. Any cracks are filled by the resin. See figure 7.19.
- A synthetic resin-impregnated liner fitted with a polyurethane inner and outer layer is fitted to a mould. The ends of the liner are fitted with a special type of rubber seal. The mould is winched into the sewer until it reaches the desired location (as observed by means of a CCTV camera), where the mould is inflated. Upon contact with moisture the special rubbers swell up to create a watertight seal between the liner and the sewer wall.

Figure 7.19 Principle of cured-in-place lining using a packer. (source: RIONED Foundation)



a. Introduction and positioning
b. Expanding and curing
c. Final situation

The main characteristics of these methods are:

- The sewer must always be cleaned before the repair.
- The end product is watertight.
- Depending on the thickness of the liner it can take over the structural strength of the original sewer.
- The sewer can remain in service during the repairs.
- The applications in ovoid section sewers are limited.
- The service life expectancy of the repaired location is high, although it ultimately depends on the local conditions.

Local injection grouting (no-dig)

The purpose of this technique is to remedy the infiltration of groundwater through pipe joints and small cracks. A hollow injection mould is introduced into the sewer. A two-component liquid compound in then pressure-injected into the pipe joint until it flows outside the sewer. The technique is based on the principle that the injected liquid expands and forms a solid mass with the surrounding soil while remaining slightly flexible.

The main characteristics of this technique (see also figure 7.20) are:

- The end product is watertight, provided certain specific conditions are met.
- The sewer can remain in service during the repairs, albeit at a reduced capacity.
- It is suitable only for sewers that are permanently below the groundwater table.
- The service life of the repair can vary greatly depending on the local conditions.
- The technique is relatively cheap.

ASSIGNMENT
Argue under which conditions injection grouting is not a suitable technique because its service life will be cut short.

Leaks may also be stopped by injecting synthetic resin mortar from ground level.

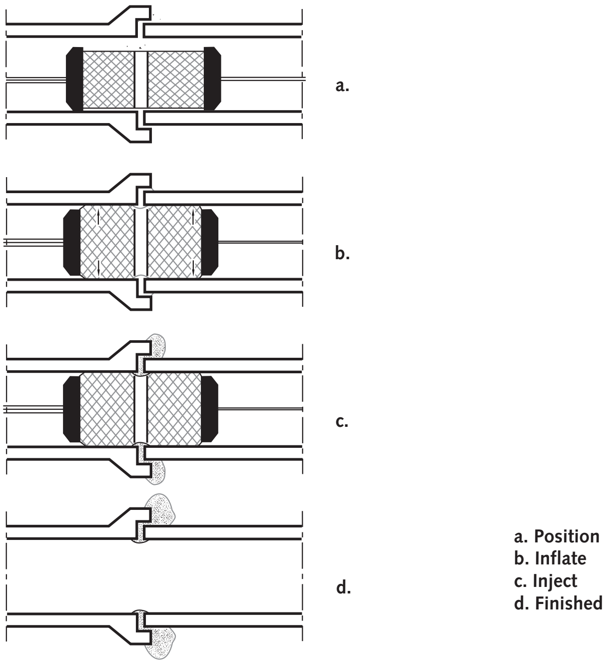


Figure 7.20 Principle of local injection grouting (source: RIONED Foundation)

Concrete jacket (dig)

A concrete jacket is applied to locally reinforce a pipe from the outside. It is necessary to dig around the sewer at the repair location.

Table 2.1 of C3000 indicates that this technique is suitable only for a limited number of defect types such as leaks, soil entering the sewer, cracks, and defects limited to a single location.

A concrete jacket is relatively simple to make, it is relatively cheap, but the improvement of the condition is limited and short-lasting.

In fact a concrete jacket is a useful application only if the following conditions are met.

- The location has no settling problems (i.e. the soil is sand).
- The existing pipeline is above the groundwater table.
- The existing pipeline is made of concrete.
- The repair is intended to be a temporary measure (maximum service life 5 years).

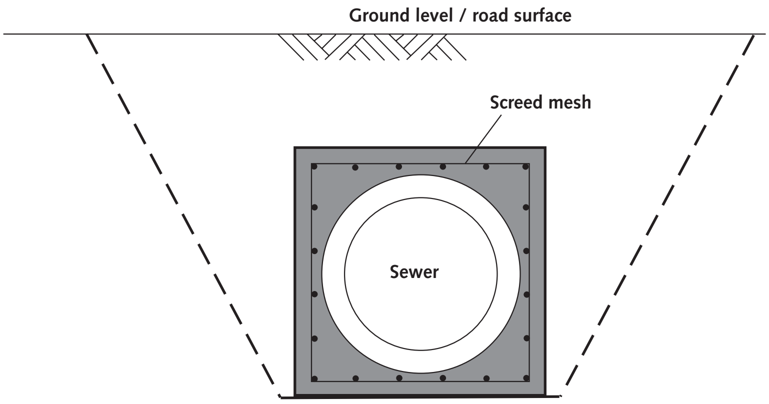


Figure 7.21 Principle of concrete jacket (source: RIONED Foundation)

ASSIGNMENT

Argue what can happen if a concrete jacket is applied in a situation in which the first two of the above criteria are not met.

7.5.3.4 Renovation

As the number of local defects increases, there comes a point at which the repair cost relative to the achievable remaining service life are such that renovation or replacement becomes cheaper. In other words, the sum of the total cost of repair exceeds the cost of renovation or replacement. Therefore it is important to find out whether there are any plans for roadworks in the near future, in which case work above ground and underground can be combined.
The use of a renovation technique is an drastic measure, which in all cases is applied using a no-dig procedure. The structural quality of the end product must be comparable to that of a new structure.

The Urban Drainage Guideline lists eight renovation techniques:

- Coatings
- Helically-wound pipe
- Pipe segments
- Cured-in-place lining method
- Rigid pipe slip lining
- Flexible pipe slip lining
- Cement spraying
- Plastic coating

We will now discuss the cured-in-place lining method and rigid pipe slip lining.

Cured-in-place lining method

This method uses a synthetic-resin impregnated sleeve which is inserted into the sewer to reline the pipeline.
This lining method has two variants, both of which can use hot water, steam, or UV light to cure the resin.

1. One side of a fibreglass sleeve is impregnated with a synthetic resin in situ. The wet sleeve is then pulled into the previously cleaned sewer and pressed against the pipe wall by means of pressurised air or water. The sleeve resin is then cured by means of hot water or steam. The sleeve has been factory-fitted with a PVC film to aid inflation by preventing air escaping from the still porous sleeve. The renovation sleeve can also consist of three layers. The intermediate layer of felt or fibreglass fabric is then impregnated with resin in situ using a heavy roller to spread the resin onto the sleeve. The outer layers consist of a PU (polyurethane) film.

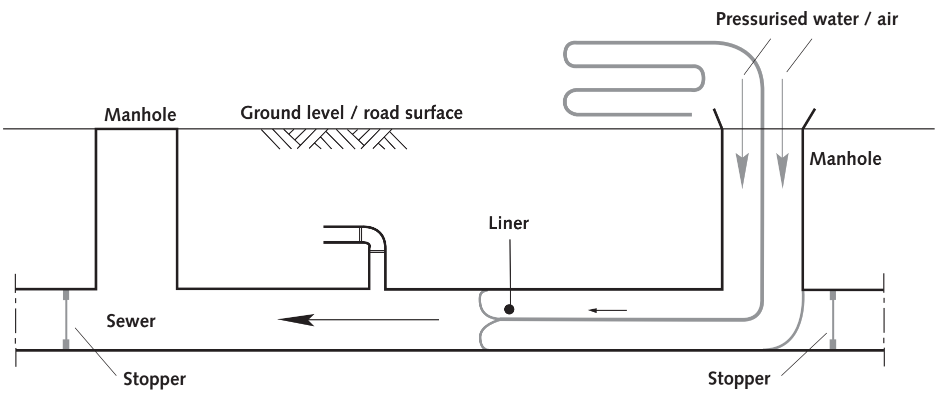


Figure 7.22 Principe of the sleeve lining method. Source: RIONED Foundation

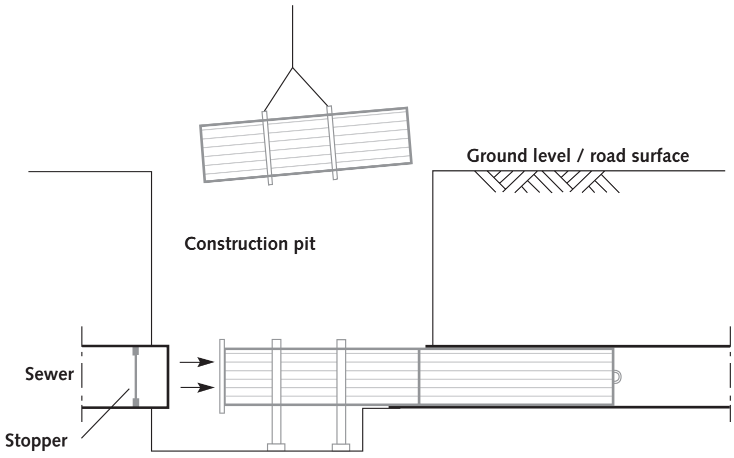
Figure 7.23 Left: Cured-in-place relining rig. Right: Fitting the sleeve. Source: Municipality of Eemnes/ Blaricum

2. This method uses a needle felt sleeve, the inside of which is impregnated with synthetic resin. First the sewer is cleaned, and then the prepared sleeve is inserted into the sewer through a manhole using a special device (an inversion pipe or collar) and water pressure, turning the sleeve inside out. The water pressure pushes the sleeve in the pipe and against the pipe wall. Once the sleeve is in position and unfolded, a circulation system heats the water inside to approximately 80°C to accelerate the chemical reaction that cures the resin. The result is a smoothly lined sewer. Instead of water, (ultraviolet) light can be used to cure the resin.

The main characteristics of the end product are as follows.
- Both variants produce a watertight lining reinforced with fibreglass fabric or needle felt. Depending on the thickness, the liner can take over the structural function of the sewer.
- The method can be used in circular section sewers with diameters from 100 mm to 3000 mm, and in ovoid section pipes up to 1200/1800 mm.
- The method is particularly suitable for use in large transport sewers in which the structural strength has been reduced by corrosion, damage, and/or cracks.
- Depending on the thickness of the materials the new pipeline can take over the full structural strength of the original sewer.
- Depending on the diameter and the method, a single renovation sleeve can cover a length of up to 500 m.
- The sleeve thickness varies between 3 mm and 42 mm, depending on the required structural strength.
- The service life expectancy of the end product is generally high, but it depends on the wall thickness in relationship to the damage sustained by the old pipe.

Rigid pipe slip lining
Slip lining is also referred to as the pipe-in-pipe method. The technique of slip lining is used to renovate a complete stretch of gravity sewer or pressure pipeline by inserting into it separate sections of plastic pipe that are joined in situ. The space between the old pipe and the newly inserted pipe is filled with light concrete or foam. The length of the new pipe section varies according to the process used. Some techniques use short pipe sections that can be introduced though a manhole. If longer pipe sections are used, a construction pit will have to be dug.
See figure 7.24.

Figure 7.24 Principle of a rigid pipe slip lining



The main characteristics of the end product are as follows.

- The pipe material is usually PE (polyethene), PVC (polyvinyl chloride), or GRP (glass-reinforced plastic). The choice of material depending in part on the chemical composition of the sewage.
- Slip lining is used in particular for situations in which the structural strength has been reduced by corrosion, damage, and/or cracks.
- Depending on the thickness of the materials the new pipeline can take over the full structural strength of the original pipeline.
- The diameter of the pipeline to be renovated must be at least 200 mm and no more than 2400 mm;
- If the sewer is more or less straight, a single construction pit can be used to insert up to several hundred metres of pipe.
- During the renovation work the sewer system will have to be taken out of service. This means that additional measures need to be taken, such as diverting the wastewater flow.
- The service life expectancy of the end product is high.

Figure 7.25 Left and right: examples of slip relining. Source: BAM and Hobas

7.5.3.5 Replacement

Replacing sewer system objects for the greater part is the same activity as the initial construction of those objects. Of course the difference is that the existing objects must first be removed. Replacing a sewer system in an existing context places special requirements on the construction work due to the on-site conditions.

The technical aspects of construction have been discussed before, in chapter 6.

If a sewer is removed and replaced by a pipe with specifications that differ from the removed sewer, this is called improvement.
Example: the existing pipe diameter is 500 mm; the diameter of the new pipe is 800 mm (to provide an increased discharge capacity).
Example: the existing pipe material is concrete; the material of the new pipe is PVC (to avoid the current concrete corrosion).

Self-assessment questions for chapter 7

1. In your own words, give a definition of the following terms: Sewer system management and operational sewer system management. System management and object management.
2. As the owner of the sewer system, the municipality generally is also the sewer management authority. It is responsible for sewer system management and for operational sewer system management. Name the tasks and responsibilities of the local council, the mayor and aldermen, and the civil service (within the municipal organisation) in this context.
3. The mayor and aldermen are responsible for implementing and reporting back on the sewer policy as defined by the local council. Before this policy results in concrete sewer system measures, a strategy is often defined. The strategy is then decided by the local council. Question: What does strategy mean in this context? Name an example of a policy objective for the sewer system and different strategies for achieving this purpose.
4. What are the four basic activities for operational sewer system management, and what is the order in which these basic activities are normally executed? Name examples of applications of the basic activities in system-focused and object-focused operational sewer system management.
5. Investigation is the first activity in operational sewer system management. Name the main activities that can be executed as part of investigation, and give a short description of what those activities consist of.
6. What kind of information or data should the sewer systems databank contain? How is this done nowadays?
7. Visual inspection is used to record the condition issues of the sewer system objects in accordance with a uniform classification system. The detail description of a condition issue is done using a class code (class 1 to class 5). Question: what is meant by a condition issue of a sewer system object? Name some examples of condition issues. What is meant by a detail description of class 5? What is meant by the action criterion?
8. The investigation into the performance of a sewer system by means of measurements and calculations can be looked at from two different points of view. In your own words, describe the two points of view and give examples of the relevant investigation activities.
9. The purpose of assessing the condition of sewer system objects is to determine the priority and the nature of any measures to be taken. Question: How does the assessment process take place, and what is meant by ‘the priority’ and the ‘nature’ of the measures to be taken?
10. What is meant by the technical service life of a sewer pipe? Can you estimate the average technical service life of concrete, PVC, and clayware sewer pipes for wastewater? Name some of the factors that affect the technical service life.
11. Maintenance, repair, renovation, and replacement are all management measures aimed at improving the condition of sewer objects. In your own words, give a short description of the purpose and the nature of these measures. For each measure include an example of a relevant technique.
12. One of the techniques used for renovating a concrete transport sewer is the cured-in-place liner method. Describe and sketch the technique. What is the difference between the two variants of the sleeve liner method? What are the strengths and weaknesses of the technique?
13. If the condition of the sewer sections and manholes makes it necessary to replace them, the normal practice is to improve the sewer system. Question: What is the difference between replacement and improvement?

Index

Websites (in alphabetical order)

www.arcadis.nl	Arcadis co.
www.betonleeft.nl	Manufacturers of concrete pipe systems, with links to members' sites and free access to the Sewer technology manual (*Handboek riolerings-techniek*, Dutch PDF only)
www.breijn.nl	Breijn Engineering co.
www.bureauleiding.nl	Information office for plastic pipeline systems
www.dhv.nl	DHV Group
www.ez.nl/Onderwerpen/Overig/Grondroerdersregeling	Information about the Underground networks information exchange act
www.grontmij.nl	Grontmij co.
www.kiviniria.net	KIVI/NIRIA institute
www.klic.nl	KLIC (Cables and pipes information centre)
www.knmi.nl	KNMI, the Royal Netherlands Meteorological Institute
www.mwhglobal.com	MWH Global co.
www.ibos-regenwater.nl	IBOS – Rainwater (interactive decision support system for the sustainable handling of rainwater).
www.nederlandleeftmetwater.nl	Dutch government site on water policy
www.nlingenieurs.nl	Nlingenieurs association
www.oranjewoud.nl	Oranjewoud co.
www.overheid.nl	Dutch government site on legislation
www.rioned.org (English access point to www.riool.net)	RIONED Foundation, with lots of information for sewerage professionals. Supporters of the RIONED Foundation get access to the Urban Drainage Guideline and the IBOS – Rainwater
www.riool.info	General information about sewer systems
www.royalhaskoning.com	Royal Haskoning co.
www.snaterse-ctm.nl	Snaterse Civil Engineering & Management co.
www.tauw.nl	TAUW co.
www.uvw.nl	Union of Water Boards, with links to all 27 water boards
www.verkeerenwaterstaat.nl	Dutch Ministry of Transport and Public works
www.vng.nl	Association of Dutch Municipalities, with links to all 441 municipalities
www.vrom.nl	Dutch Ministry of Public Housing, Spatial Planning and Environmental Management
www.waternetwerk.nl	Dutch Association of Water Professionals
www.witteveenbos.nl	Witteveen+Bos co.

Addresses and websites of participating engineering companies

DHV B.V.
P.O. box 1132, 3800 BC Amersfoort, the Netherlands
www.dhv.nl

Haskoning Nederland B.V.
P.O. box 151, 6500 AD Nijmegen, the Netherlands
www.royalhaskoning.com

Grontmij
De Molen 48, 3994 DB Houten, the Netherlands
www.grontmij.nl

Snaterse Civiele Techniek & Management B.V.
P.O. box 183, 3850 AD Ermelo, the Netherlands
www.snaterse-ctm.nl

MWH B.V.
P.O. box 270, 2600 AG Delft, the Netherlands
www.mwhglobal.nl

Breijn B.V.
P.O. box 37, 5240 AA Rosmalen, the Netherlands
www.breijn.nl

Witteveen & Bos
P.O. box 10095, 1301 AA Almere, the Netherlands
www.witteveenbos.nl

Arcadis
P.O. box 410, 2130 AK Hoofddorp, the Netherlands
www.arcadis.nl

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P.O. box 10044, 1301 AA Almere, the Netherlands
www.oranjewoud.nl

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www.tauw.nl

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P.O. box 133, 6710 BC Ede, the Netherlands
www.riool.net